TEQIP-III Short Course on Systems Analysis of Biofuels and Bioproducts

Module 2: Technical Feasibility and Resource Sustainability Assessment

Ganti S. Murthy
Professor
Discipline of Biosciences and Biomedical Engineering,
Indian Institute of Technology-Indore
Email: Ganti.Murthy@iiti.ac.in

1

Goals of this Lecture

Introduce the Technical Feasibility and Resource Sustainability Analysis

Learning Objectives

By the end of this lecture, you must be able to:
1. Able to perform basic technical feasibility analysis
2. Calculate the resources (land, water and nutrient) needed for any technology

2

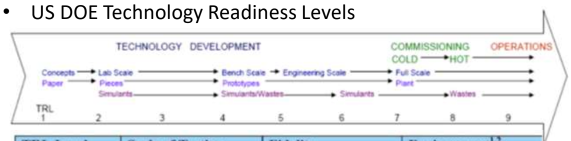
Technical Feasibility

- Aspects of technical feasibility analysis
  - Technical Feasibility
  - Schedule Feasibility
  - Operational Feasibility
  - Economic Feasibility
- Estimating theoretical maximum and best-case scenarios
- Using alternative approaches to assess technical feasibility

3

Technical Feasibility

- US DOE Technology Readiness Levels



TRL Level	Scale of Testing	Fidelity	Environment[1,2]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot Scale	Similar	Relevant
5	Lab/Bench	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

[1] Simulants should match relevant physical and chemical properties
[2] Testing with as wide a range of actual waste as practicable; and consistent with waste availability, safety, ALARA, cost, and project risk is highly desirable

4

Biorefinery Complexity Index

- IEA task force 42 proposed a biorefinery complexity index inspired by a Nelson's Complexity Index (NCI) used to indicate the complexities in petroleum refineries.
- Feature Complexity (FC) = 10-TRL
- Assigns FC levels to
  - Platforms
  - Feedstocks
  - Products
  - Processes

5

Biorefinery Complexity Index

TRLs for Platforms

C6 sugars (9), C5 sugars (7), C6 and C5 sugars (7), oils (9), fiber (7), bagasse (9) pulp (9) lignin for pyrolysis (6), lignin from hydrolyses (7) , lignin and C6 sugars (8) pyrolysis oils and slurry (4), syngas (9), black/sulfite liquor (8-9), biogas (9), hydrogen (9), electricity and heat (9), biomethane (8) and green pressate (7)

TRLs for Feedstocks

Agricultural produce: Starch rich feedstocks (maize, wheat, potatoes, cassava and tapioca) (9), oil seeds (9), sugarcane and other sugar crops (9), bagasse (9), microalgae (4), agricultural residues (corn stover, wheat straw, rice straw, grass straw) (7-8)

Waste feedstocks: effluents from dairy industries (9), municipal solid waste (8-9), municipal waste water (8-9), fruit processing wastes (citrus peels, coffee processing waste, tea processing waste) (9), food industry effluents (vegetable processing, food product manufacturing) (9), animal manure (9)
Wood Industry Products: saw mill residues (9), wood chips (9), dedicated energy crops (7-8), hardwoods (7-8), softwoods (7-8), effluents from paper processing (black/sulfite liquor) (8)

6

Biorefinery Complexity Index

TRLs for Products

Fuels and energy: Ethanol (9), biodiesel (9), biogas (9), biomethane (8), syngas and FT-biofuels (8), electricity and heat (9), process heat and steam (9).
Food and Feed: sugar (9), Omega 3 from algae (6), animal feed (9)
Materials: biomaterials from grass fibers (7), bioplastics (8), paper (9), pulp (9)
Chemicals: Waxes from wood (6), turpentine (9), tall oil (9), CO_2 (9), hydrogen from wood (9), Amino acids (mix) from grass (8), lactic acid from grass (7), phenols from lignin (6), methanol from straw (9), glycerin (9)
Polymers and plastics: Bio PET (9), PLA, PHA,
Other valuable products: Limonene, pectins, intermediate platform chemicals

TRLs for Processes

Thermo-chemical process: lignin pyrolysis (6), straw pyrolysis (7), combustion of various feedstocks (8-9), gasification of various feedstocks (8)
Biochemical process: Anaerobic digestion (9), Algae anaerobic digestion (7), enzymatic hydrolysis of starch (9), enzymatic hydrolysis of cellulose in various feedstocks (7-8), aerobic/anaerobic fermentation C6 (9) and C5 (6-7) sugars.
Chemical processes: Hydroprocessing (9), hydrolysis of wood (7), hydrolysis of straw (8), steam reforming (9), methanation (9), methanol-synthesis (9), FT-synthesis (9), esterification (9)

Mechanical processes: oil extraction (8-9), algae oil extraction (7), pretreatment of straw (8), pretreatment of wood chips (7), mechanical fractionation of starch (9), ligncellulose (8) and green pressate (8), pressing of crops (8-9), filtration of green pressates (8), crystallization of C6 sugars (9), upgrading FT-raw product (7), biogas upgrading (8), drying grass fibres (8), DDGS drying (9), Distillation (9), oil separation (9), separation of liquid/solid fertilizer (9), generic separation (8), mechanical treatment (9), paper making (9), pulp production (9), chipping and debarking (9), processing straw for pyrolysis (7)

7

Biorefinery Complexity Index

Example

- Calculate the BCI for a Corn dry grind ethanol process
- FCplatform =1 (10-9=1).
- FCfeedstocks=1,
- FCProducts, ethanol=1 and FCProducts, DDGS=1.
- FCprocess,sizereduction=1, FCprocess,hydrolysis=1, FCprocess,fermentation=1, FCprocess,distillation=1 and FCprocess,drying=1.
- BCI =FCplatform (1) +FCfeedstock (1) + FCproduct (1+1) + FCprocess (1+1+1+1+1) =9.

Based on these numbers, the BCP for a corn dry grind ethanol process can be specified as BCP =9 (1/1/2/5).

8

Land and Water Use

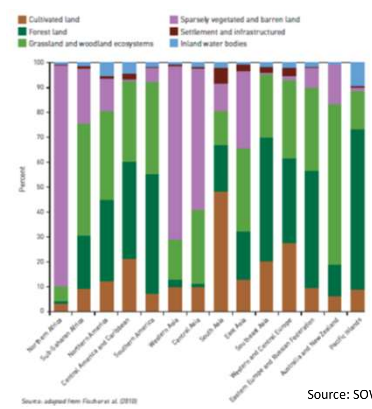
- Global Land Area: 13.2 billion ha
  - Arable Land: 1.6 billion ha (12%)
  - Forest: 3.7 billion ha (28%)
  - Grasslands and woodlands: 4.6 billion ha (35%)

- Renewable global water resources: 42, 000 Km^3/year
- Human use from rivers and aquifers: 3,900 Km^3/year (40% consumptive use)
  - Irrigation: 2710 Km^3/year (70%)
  - Industrial use: 741 Km^3/year(19%)
  - Municipal sector: 429 Km^3/year(11%)

Source: SOWLOW FAO Report

9

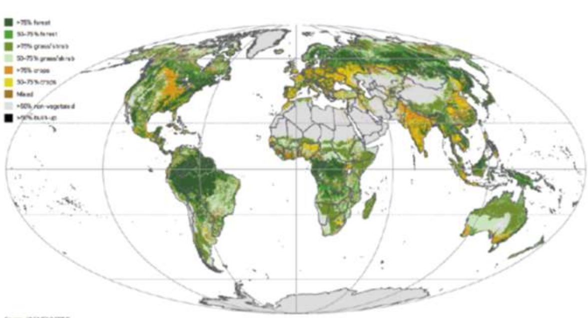
Land Use and Land Cover



Source: SOWLOW FAO Report

10

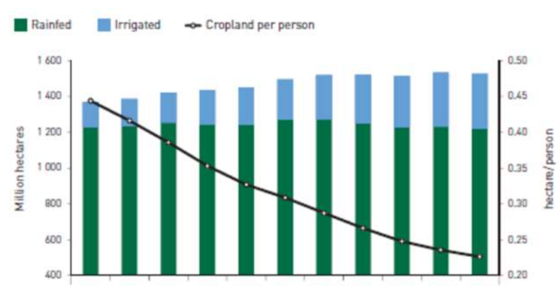
Land Use and Land Cover



Source: SOWLOW FAO Report

11

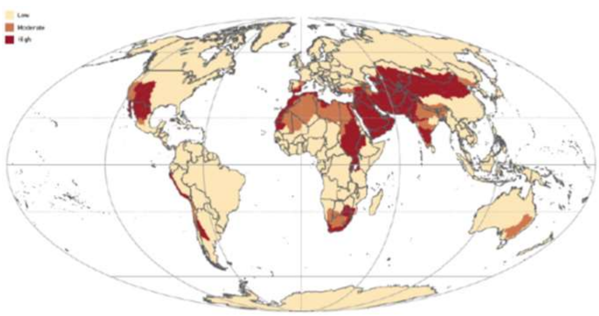
Arable Land



Source: SOWLOW FAO Report

12

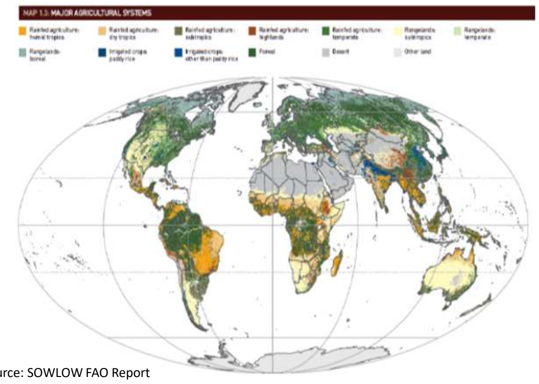
Physical Water Scarcity by Major River Basins



Source: SOWLOW FAO Report

13

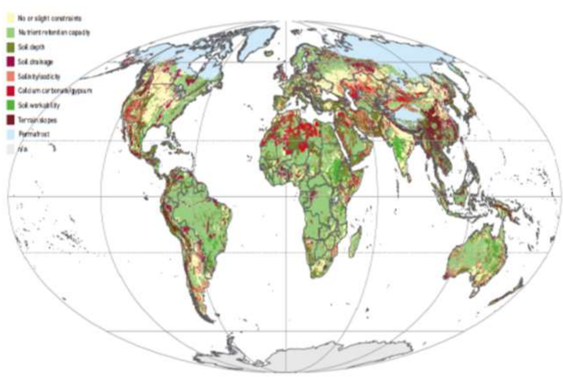
Major Agricultural Systems



Source: SOWLOW FAO Report

14

Dominant Constraints for Low-input Farming



Source: SOWLOW FAO Report

15

World Capacity of NPK Nutrients

Table 1. Total world nutrient capacity of ammonia, phosphoric acid and potash, 2015-2020 (thousand tonnes)

Year	2015	2016	2017	2018	2019	2020
Ammonia (NH_3) as N	174 781	181 228	185 222	186 804	186 920	188 310
Phosphoric acid (H_3PO_4) as P_2O_5	57 422	58 385	60 955	61 995	63 036	64 677
Potash as K_2O	52 942	55 974	58 111	61 576	62 136	64 486
Total (N+ P_2O_5+K_2O)	285 145	295 587	304 287	310 374	312 092	317 474

Source: FAO Fertilizer 2020 Outlook Report

16

World Supply of NPK Nutrients

Table 2. World supply of ammonia, phosphoric acid and potash, 2015-2020 (thousand tonnes)

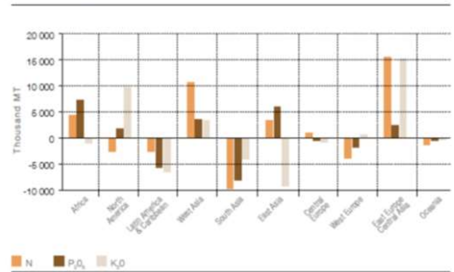
Year	2015	2016	2017	2018	2019	2020
Ammonia (NH_3) as N	154 773	158 850	166 402	168 987	169 693	170 761
Phosphoric acid (H_3PO_4) as P_2O_5	47 424	48 394	49 558	51 190	52 361	53 078
Potash as K_2O	43 571	42 772	44 868	47 249	48 898	49 545
Total (N+ P_2O_5+K_2O)	245 768	250 016	260 828	267 426	270 952	273 384

Source: FAO Fertilizer 2020 Outlook Report

17

World Supply of NPK Nutrients

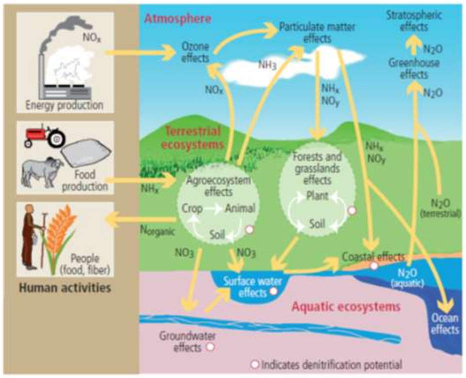
Figure 1. Anticipated nutrient balances in 2020



Source: FAO Fertilizer 2020 Outlook Report

18

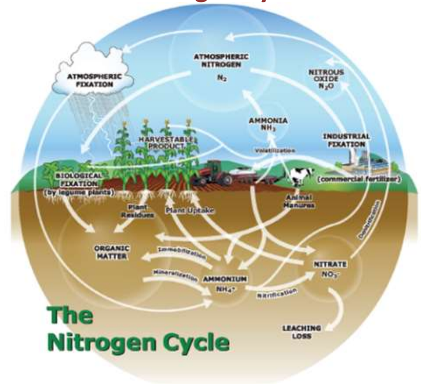
Nitrogen Cascades



Source: Reetz 2016 Fertilizers and Their Efficient Use. International Fertilizer Association

19

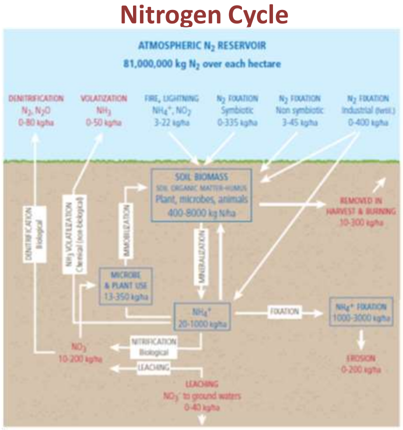
Nitrogen Cycle



Source: Reetz 2016 Fertilizers and Their Efficient Use. International Fertilizer Association

20

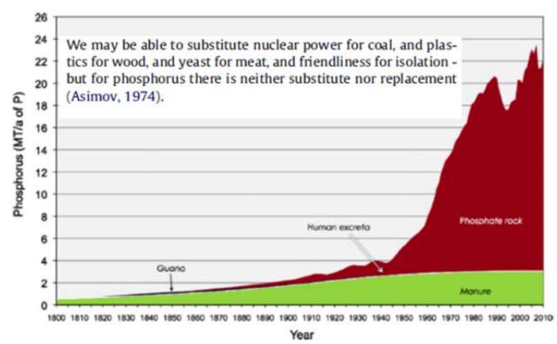
Nitrogen Cycle



Source: Reetz 2016 Fertilizers and Their Efficient Use. International Fertilizer Association

21

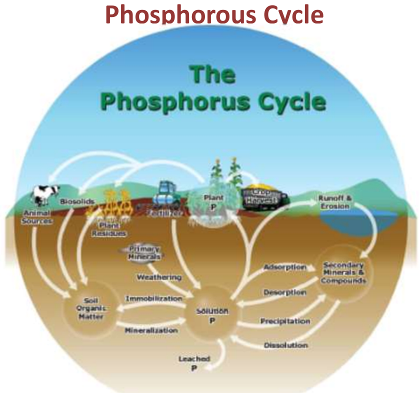
Phosphorous Supply



Source: Ashley et al. 2011

22

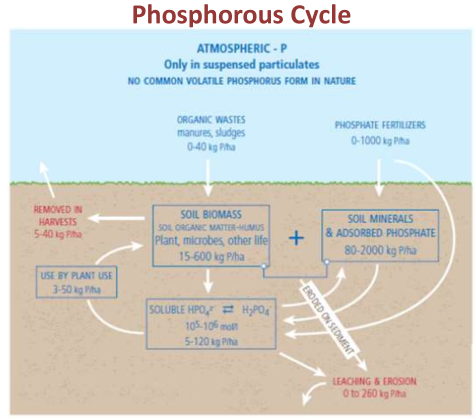
Phosphorous Cycle



Source: Reetz 2016 Fertilizers and Their Efficient Use. International Fertilizer Association

23

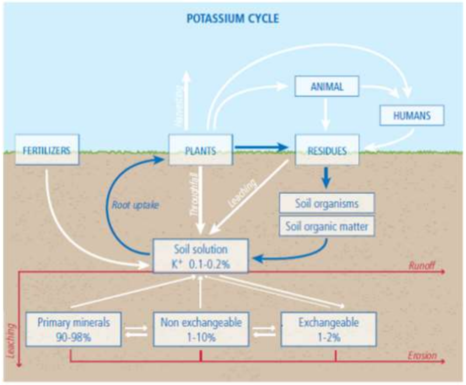
Phosphorous Cycle



Source: Reetz 2016 Fertilizers and Their Efficient Use. International Fertilizer Association

24

Potassium Cycle



Source: Reetz 2016 Fertilizers and Their Efficient Use. International Fertilizer Association

25

Nutrient Management: BMPs

Table 4. Components of the 4R Nutrient Stewardship system.

Component	Goal
Right source	Provide plant-available forms, and a balanced supply of all essential nutrients. Take advantage of various formulations that offer improved efficiency and reduce environmental consequences.
Right rate	Ensure an adequate supply of all essential nutrients to meet plant demand.
Right time	Manage nutrient applications to match the interactions of crop uptake, soil supply, environmental risks, and field operation logistics.
Right place	Consider root-soil dynamics and nutrient movement, and manage spatial variability within the field to meet site-specific crop needs and minimize potential losses from the field.

Source: Reetz 2016 Fertilizers and Their Efficient Use. International Fertilizer Association

26

References

- Land and water
  - https://www.ers.usda.gov/topics/farm-practices-management/
  - https://water.usgs.gov/edu/wuir.html
  - http://www.globalagriculture.org/report-topics/water.html
  - http://www.globalagriculture.org/fileadmin/files/weltagrarbericht/AquastatWithdrawal2014.pdf
  - https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Reprint_14-16.pdf
  - http://www.fao.org/land-water/databases-and-software/en/
  - http://www.fao.org/3/a-i1688e.pdf
  - https://pubs.usgs.gov/circ/1405/
  - http://oamk.fi/~mohameda/materiaali16/Water%20and%20environmental%20management%202015/2011_Brown_Matlock_Water-Availability-Assessment-Indices-and-Methodologies-Lit-Review.pdf
  - http://waterfootprint.org/en/water-footprint/what-is-water-footprint/
  - http://waterfootprint.org/media/downloads/TheWaterFootprintAssessmentManual_2.pdf
  - http://www.sciencedirect.com/science/article/pii/S1470160X14002660 Water footprint benchmarks for crop production: A first global assessment
  - http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0032688
  - https://water.usgs.gov/watuse/wuglossary.html
- Nutrients
  - http://www.fertilizer.org/imis20/images/Library_Downloads/2016_ifa_reetz.pdf?WebsiteKey=411e9724-4bda-422f-abfc-8152ed74f306&=404%3bhttp%3a%2f%2fwww.fertilizer.org%3a80%2fen%2fimages%2fLibrary_Downloads%2f2016_ifa_reetz.pdf
  - http://www.fertilizer.org/statistics
  - http://ifadata.fertilizer.org/ucSearch.aspx
  - http://www.theglobaleconomy.com/rankings/fertilizer_use/
  - https://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/fertilizer-use-markets/
  - https://ourworldindata.org/yields-and-land-use-in-agriculture/

27

TEQIP-III Short Course on Systems Analysis of Biofuels and Bioproducts

Module 2: Technical Feasibility and Resource Sustainability Assessment

BREAK

Ganti S. Murthy
Professor
Discipline of Biosciences and Biomedical Engineering,
Indian Institute of Technology-Indore
Email: Ganti.Murthy@iiti.ac.in

28

First Generation Biofuels Feasibility Analysis

29

Corn Dry Grind Ethanol in the US

Background

- Corn dry grind ethanol process is currently used in the US to produce 60 billion L/year (~15.8 billion gal/year) of ethanol per year accounting for 58% of the global production
- This process uses almost 35% of the US corn production. Each bushel of corn (25.424 kg or 56 lbs) can produce 10.62 L or 2.8 gal of ethanol.

30

First Generation Biofuels Feasibility Analysis

<u>The goal of this analysis is to:</u>

- Determine the levels of ethanol that can be produced without major disruption in the corn markets or expanding the area of cultivation significantly.

Data
Average US corn yield: 11.46 tons/ha (181.3 bu/acre)
US corn, grain- harvested: 32.708 million ha (81.77 million acres)
US crop land: 152.26 million ha
Corn to ethanol conversion: 0.4273 L/Kg (2.87 gal/bu)
DDGS production: 0.2928 kg/kg corn or 0.685 kg/L ethanol
Gasoline:Ethanol energy density equivalency ratio= 1.424
US gasoline needs: 3.404 billion barrels=142.98 billion gal=541.735 billion L/year
Number of cattle in US: 92 million heads.
1 gal =3.785 L

31

First Generation Biofuels Feasibility Analysis

Calculations

- Ethanol equal to 100% current gasoline needs
  = 541.735 billion L/year x 4.424 =771.5 billion L/year
- Ethanol equal to 50% current gasoline needs
  = 385.75 billion L/year
- Total corn production, TCP
  = Average US corn yield x US corn crop area
  =11.46 tons/ha x 32.708e6 ha = 374.8 million tons/year
- Ethanol potential with current corn production
  = Average US corn yield x US corn crop area x Corn to ethanol conversion
  =11.46e3 kg/ha x 32.708e6 ha x 0.4273 L/kg =160.16 billion L/year (42.31 billion gal/year)
- Max. Ethanol potential with corn production on all arable lands
  = Average US corn yield x US arable land area
  =11.46e3 kg/ha x 152.26e6 ha x 0.4273 L/kg
  = 745.6 billion L /year (197 billion gal./year)

32

First Generation Biofuels Feasibility Analysis

- Area needed to produce ethanol to meet 100% current gasoline needs
  = Ethanol equal to 100% current gasoline needs /(Average US corn yield x Corn to ethanol conversion)
  =771.5 billion L/year /(11.46e3 kg/ha x 0.4273 L/kg)=157.6 million ha.
- Area needed to produce ethanol to meet 50% current gasoline needs
  = Ethanol equal to 100% current gasoline needs /(Average US corn yield x Corn to ethanol conversion)
  =385.75 billion L/year /(11.46e3 kg/ha x 0.4273 L/kg)= million ha.
- Area needed to produce 15 billion gal/year ethanol
  =(15 billion gal/year x 3.785 L/gal) /(11.46e3 kg/ha x 0.4273 L/kg)
  =11.6 million ha
- Amount of DDGS produced for 15 billion gal ethanol
  = 15 billion gal/year x 3.785 L/gal x 0.685 kg/L ethanol
  = 38.89 million tons
- Number of cattle that can be fed the DDGS :
  38.89 million tons/0.548 tons/head =71 million cattle heads

33

First Generation Biofuels Feasibility Analysis

<u>Results:</u>

- The total area needed to meet gasoline needs of the US (157.6 million ha) is greater than the arable land available (152.26 million ha).
- The land area needed to meet 50% of the gasoline needs (78.78 million ha) is greater than the crop land dedicated to US corn production (32.708 million ha).
- Area needed to produce 56.78 billion L/year (15 billion gal/year) ethanol is 11.6 million ha, which is about 35% of the US corn cropping area

34

First Generation Biofuels Feasibility Analysis

<u>Conclusions :</u>

- It is infeasible to meet 100% or even 50% of the US gasoline needs using ethanol from corn.
- It is feasible to produce 56.78 billion L/year (15 billion gal/year) with existing land resources, but the coproduct utilization needs to be looked carefully to avoid potential market saturation scenarios.

35

Second Generation Biofuels Feasibility Analysis

36

Cellulosic Ethanol Production in the US

Background
- Agricultural residues such as corn stover, wheat straw and barley straw among others are considered as potential feedstocks for producing second generation cellulosic ethanol.

The goal of this analysis is to:
- Determine the levels of ethanol that can be produced from corn stover and other agricultural residues without any increase in cultivated area.

37

Cellulosic Ethanol Production in the US

Data
- Projected corn stover at<$80/ton is 112.2 million tons and 129 million tons of all agricultural residues
- Corn Stover Composition (dry basis):

Glucan	Xylan	Lignin	Ash	Acetate	Protein
35.05	19.53	15.76	4.93	1.81	3.1
Extractives	Arabinan	Galactan	Mannan	Sucrose	
14.65	2.38	1.43	0.6	0.77	

Assumptions
- Basis: 1 dry ton.
- Pretreatment and hydrolysis efficiency is 80%
- Inhibitors generation: 1% from hexoses and 2% from pentoses
- Fermentation efficiency: Hexose and pentose fermentation efficiency are 98 and 60 % respectively.
- Distillation efficiency is 99%.

38

Cellulosic Ethanol Production in the US

Calculations
- Hexoses = Biomass* Glucan* ηhydrolysis*Hydrolytic gain*(1-inhibitor production)
- Pentoses=Biomass* Xylans* ηhydrolysis*Hydrolytic gain*(1-inhibitor production)
- Ethanol = Hexoses * ethanol yield * hexose fermentation efficiency + Pentoses * ethanol yield * pentose fermentation efficiency
- Ethanol (L) = Ethanol (Kg) * distillation efficiency / ethanol density (kg/L)
- Overall Ethanol yield= Ethanol/Basis = 0.2605 L/Kg
- Total corn ethanol = Average US corn stover production x Ethanol yield =29.23 billion L/year (7.71 billion gal/year)

39

Cellulosic Ethanol Production in the US

Results:
- Based on the total US gasoline needs of 541.735 billion L/year, the corn stover ethanol represents a 5.4 % of the total gasoline needs.
- Potential ethanol production from all agricultural residues will be 33.6 billion L/ year represents a 6.2% of the total US annual gasoline needs.

40

Cellulosic Ethanol Production in India

- India needs 232 billion L of petrol/year
- India produces about 165 MMT of agricultural residues.

Questions
- What is the potential of cellulosic ethanol in India?
- Where can we produce it?
- What are the top feedstocks?

Assume
- 260L/MT biomass ethanol yield

41

Cellulosic Ethanol Production in India

State	Biomass Generated (MMT)	Bioethanol potential
Uttar Pradesh	138.0	35889.7
Maharashtra	81.7	21250.1
Andhra Pradesh	44.2	11494.9
Punjab	41.5	10785.3
Tamil Nadu	40.3	10480.9
Karnataka	39.1	10164.1
Madhya Pradesh	38.1	9904.8
Rajasthan	33.8	8793.3
Gujarat	30.9	8037.1
Total	623.4	162077.4

However
- Agricultural residues are used as cattle feed and for cooking.
- What is the real potential when accounting for the farmers needs?

42

Cellulosic Ethanol Production in India

- Notice something here? …Punjab is missing.

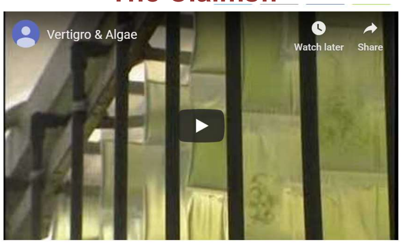
State	Biomass Generated (MMT)	Bioethanol potential
Uttar Pradesh	38.4	9980.6
Maharashtra	28.5	7409.8
Tamil Nadu	13.4	3474.4
Andhra Pradesh	11.7	3038.7
Karnataka	11.5	2994.7
Gujarat	10.9	2828.7
Madhya Pradesh	9.3	2418.1
Rajasthan	7.2	1876.3
West Bengal	6.3	1646.9
Total	164.5	42771.1

43

Algal Biofuels Feasibility Analysis

44

The Claims!!



Glen kertz grows algae in bags suspended in a greenhouse. Oil is extracted and turned into biofuel. The yield, according to Kertz, is 100,000 gallons of algae fuel per acre per year. Corn, Kertz says, yields 20 to 30 gallons.

BIOFUELS

8,571,428 Gallons of Algae Oil Per Acre!

BARD Algae says it can squeeze thousands of times more oil out of an acre of algae than others. Competitors and scientists are skeptical.

ERIC WESOFF | NOVEMBER 09, 2009

8,571,428 Gallons of Algae Oil Per Acre!

18

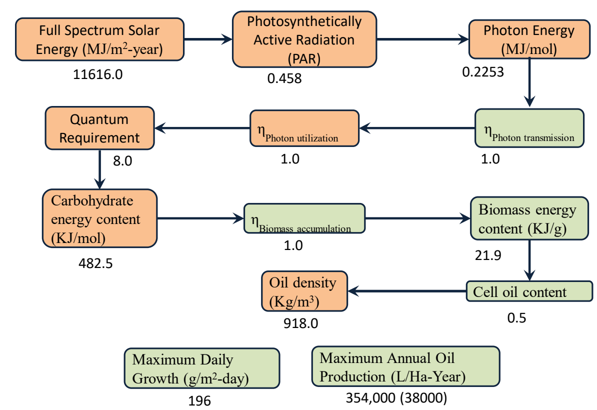
Biofuel from algae

It is reported that algae yield 30 times more energy per acre than land crops such as soybeans and some estimate even higher yields up to 15000 gallons per acre. It keeps the earth clean and free from pollution as these algal biodiesel fuels

than 60 per cent of their own biomass) of lipids. Microalgae have the highest oil yield among various oil plants. It can produce up to 100,000 lts oil per hectare per year, whereas palm, coconut, castor and sunflower produce up to 5950, 2689, 1413 and 9521 per hectare per year, respectively.

45

Production Estimates: Model



Ref: Weyer et al. 2010

46

Production Estimates: Model

Description	Units	Th. Max	Best	Open Ponds		PBR	
				min	max	min	max
Full spectrum solar energy	MJ/sq.m-year	11616.0000	5623.0000	4700	4700	4700	5621
PAR	-	0.4580	0.4580	0.458	0.458	0.458	0.458
Photon Energy	MJ/mol	0.2253	0.2253	0.2253	0.2253	0.2253	0.2253
$\eta_{Photon\ transmission}$	-	1.0000	0.9500	0.8	0.9	0.95	0.95
$\eta_{Photon\ utilization}$	-	1.0000	0.5000	0.5	0.5	0.7	0.7
Quantum requirement	-	8.0000	8.0000	8	8	8	8
Carbohydrate energy content	KJ/mol	482.5000	482.5000	482.5	482.5	482.5	482.5
$\eta_{Biomass\ accumulation}$	-	1.0000	0.5000	0.5	0.7	0.6	0.8
Biomass energy content	KJ/g	21.9000	21.9000	21.9	21.9	21.9	21.9
Cell oil content	-	0.5000	0.5000	0.1	0.15	0.15	0.25
Oil density	Kg/m3	918.0000	918.0000	918	918	918	918

Ref: Weyer et al. 2010

47

Production and Processing Alternatives

Production Metric	Units	Th. Max	Best	Open Ponds		PBR	
				min	max	min	max
Maximum daily growth	g/sq.m-day	178.2	20.5	14.4	22.7	28.8	45.9
Annual oil production	L/ha-year	354202	40722	5733	13543	17155	45592
Annual oil production	gal/ac-year	37383	4298	605	1429	1811	4812

Processing	Fuel	Max Yield (Kg or L/Kg biomass)	Efficiency	HHV (MJ/L or MJ/kg)
Direct Combustion	Biomass	1.0 of biomass	80	18.15
Solvent Extraction	Biodiesel	1.0 of lipid content	80	35.7
Anaerobic digestion	Biogas (62% CH_4)	475.8 L/Kg of biomass (8 cu ft/lb)	95	0.02375
Fermentation	Ethanol	0.51 of carbohydrate	85	23.4
Thermochemical conversion (fast pyrolysis)	Biooil	0.553 of biomass	90	33.64

Ref: Weyer et al. 2010.

48

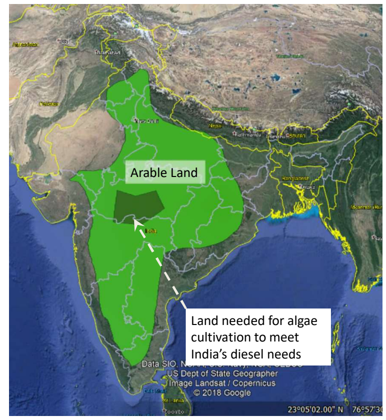
Algal Biodiesel/Biocrude: India Case Study

Algal Biodiesel Target	9.29E+10	L/year
Algae Needed	8.12E+08	MT/year
Land area needed	8.44E+06	ha/year
Carbon dioxide needed	1.49E+09	MT/year
Nitrogen needed	5.69E+07	MT/year
Phoshphorous Needed	3.25E+06	MT/year
Water for ET	7.39E+10	m3/year
Total water Requirement	7.48E+10	m3/year

Algal biofuels Water requirement	805	L/L diesel
Land Area (% of arable land)	6	%
Nitrogen Requirements (% of total Nitrogen fertilizers)	335	%
Phosphorous Requirements (% of total Phosphorous fertilizers)	111	%
Number of 1000 MW power plants	183	
Algal hydrochar produced	4.06E+08	MT/year

49

The Promise of Algae



50

EROEI and EROWI for Different Fuels

	Water usage (L/MJ)	EROWI (MJ/L)	EROEI (MJ/MJ)	Net EROWI
Nuclear Electric	1.162(0.145)	0.861(1.517)	10	0.775 (1.137)
Coal Electric	0.560(0.488)	1.786 (2.049)	-	-
Conv. Diesel	0.0035	285.3	5.01	228.4
		Biodiesel		
Rapeseed	100-175	0.010-0.0057	2.33	0.0057-0.0033
Algae (Ponds)	20.142*	0.004965	3.33	0.03475
		Ethanol		
Sugarcane	38-156	0.026-0.0065	8.3	0.023-0.0057
Corn	73-346	0.014-0.0029	1.38	0.0039-0.00081
		Lignocellulosic Crops		
Ethanol	11-171	0.091-0.0058	4.55	0.0071-0.0045
Hydrogen	15-129	0.067-0.0078	4.67	0.053-0.0062
Electricity	13-195	0.077-0.0051	5.0	0.062-0.0041

*20142 L/ 4 days ~25 people (201 L/person-day)

Data from:Mulder et al. 2010. AmBio. 39:30-39. and Sander Murthy. 2010. IJLCA.15:704-714

51

EROEI and EROWI for Algal Fuels

Scenario	Energy Output (MJ)	Energy Input (MJ)	Net Energy	EROEI (NER)	Water Usage (L/MJ)	EROWI	Net EROWI
Base case	10971.77	3291.96	7679.81	3.33	20.142 (0.403)	0.05 (2.48)	0.035 (1.74)
Improved Harvesting	10971.77	1105.51	9866.26	9.925	20.142 (0.403)	0.05 (2.48)	0.045 (1.74)
Without Coproduct Credits	1000	3291.96	-2291.96	0.308	20.142 (0.403)	0.05 (2.48)	-0.114 (-5.69)
Waste Water/ Sea Water	10971.77	1105.51	9866.26	9.925	0.1	10	9.25

*Base case as in Sander and Murthy (2010). 1000MJ ~27.89L (7.36 gal) Biodiesel
** Improved harvesting assumes a 75% reduction in energy to harvest and drying algae.
*** Numbers in parentheses indicate photobioreactor assuming a 50 times lower water consumption than an equivalent open pond.

52

Data from: Sander and Murthy, 2010. IJLCA. 15:704-714

52

Technical Feasibility: Fun Problem

- India needs 4 million barrels of petrol/day. Calculate the area needed to meet the ethanol needed to replace petrol in India?
- What if the crop is changed to Sugarcane?
- What about Algae?

53

Goals of this Lecture

Introduce the Technical Feasibility and Resource Sustainability Analysis

Learning Objectives

By the end of this lecture, you must be able to:

1. Able to perform basic technical feasibility analysis
2. Calculate the resources (land, water and nutrient) needed for any technology

54

TEQIP-III Short Course on
Systems Analysis of Biofuels and Bioproducts

Module 2: Technical Feasibility and Resource Sustainability Assessment

THANK YOU

Ganti S. Murthy
Professor
Discipline of Biosciences and Biomedical Engineering,
Indian Institute of Technology-Indore
Email: Ganti.Murthy@iiti.ac.in

55