NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Evaluation of Algal Biofuel Potential in India

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APEC Workshop on Algal Biofuels

September 12th, 2011
San Francisco, CA

India Biofuels Collaboration

- Led by the U.S. Department of Energy's (DOE) Office of the Biomass Program
- Initiative designed to support the biofuels development and deployment activities in India through collaborative technical efforts
- Seeking to energize and further develop U.S.-India relations under the bilateral Energy Dialogue
- Memorandum of Understanding on Cooperation in the Development of Biofuels signed between U.S. DOE and India's Ministry of New and Renewable Energy (MNRE)

India Biofuels Collaboration

Key partners

- MNRE and its public-private sector Core Group on Biofuels
- Indian Oil Corporation (IOC, Indian state-owned oil and gas company)
  - IOC accounts for 47% of petroleum products market, 40% of refining capacity and 67% downstream sector pipelines capacity in India
  - IOC owns and operates 10 of India's 19 refineries with a combined refining capacity of 60.2 million metric tons per year

Project Overview

Purpose

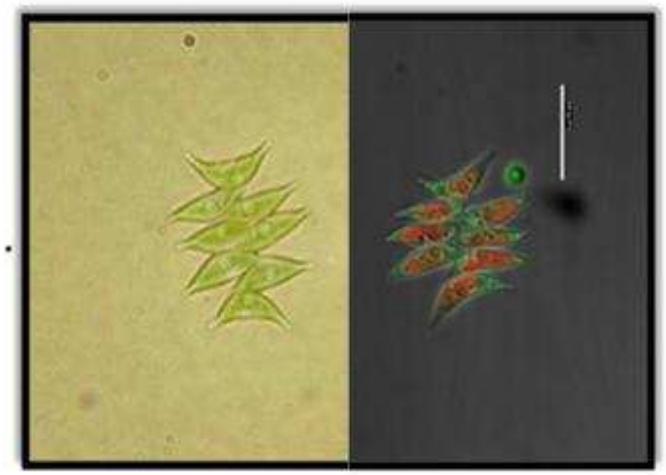
Provide understanding of the resource potential in India for algae biofuels production and assist policy makers, investors, and industry developers in their future strategic decisions.

The study integrates relevant resource data from various public and private institutions in India and it uses state of the art geographic information systems (GIS) technology to analyze the collected information and visualize the results.

Why Biofuels in India?

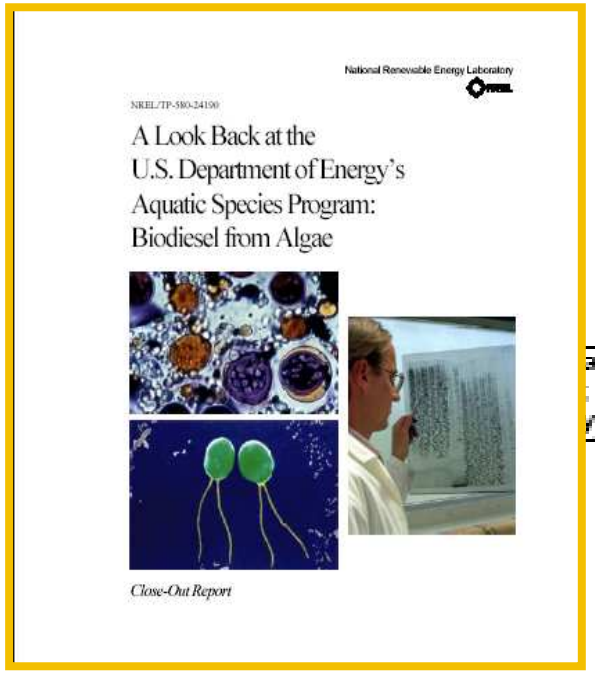
- Rapidly growing demand for oil, 70% is imported
- India is world's 4th largest emitter of CO_2 (2006)
  - 1,510 Mt, or 5% of world total
  - Expected to increase 3-5x by 2031
- Diesel-driven economy
  - Diesel accounts for 40% of petroleum used
  - ~5x the size of the gasoline market
- Interest in alternative diesel
  - Sources such as cellulosic biomass, *Jatropha*, lignin, algae
- Biofuels Policy (Dec. 2009) calls for blending at least 20% biofuels with diesel and gasoline by 2017
- Rural development is a priority
- Excellent resource potential

Why Pursue Fuels from Algae?



- Algae can produce more lipids per acre than terrestrial plants -- *potentially 10x - 100x*
- Can use marginal, non-arable land
- Can use saline/brackish water
- No competition with food, feed, or fiber
- Can utilize large waste CO_2 resources
- Potential to displace significant amount of diesel and jet fuel usage
- An algal biorefinery could produce oils, protein, and carbohydrates and a variety of other products

Why NREL?



DOE's Aquatic Species Program 1978-96

1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996

Caribbean, NM,CO, UT, FL, HI, NE, AL

CO, UT

CO, AL,MI

AZ,CA, NV,NM, TX,UT

UT, WA, CO, CA, NV

Collection, Screening, Characterization

By 1987, over 3,000 strains of algae had been collected.

al saline
Temp-
Gradient

Nile Red lipid screening

Biochemistry, Physiology of Lipid Production

Isolation and characterization of ACCase enzyme

N-deficiency lipid trigger

Si-deficiency lipid trigger

Link between Si-deficiency and ACCase

Genetic Engineering of Algae

Transient expression of foreign gene in algae using protoplasts

1st successful genetic transformation of diatom

Outdoor Culture Studies and Systems Analysis

Algae Production in Wastewater Treatment

<100 sq.m. Pond Studies (CA, HI)

1000 sq.m. Pond Study (NM)

Systems Analysis and Resource Assessment

NREL's Diverse Algal Projects

Eleven internally funded algal biofuels projects since 2008.

Chevron CRADA

Seed Grant

Algal Biofuels Technology Roadmap
Partnerships in Canada and Israel
Biorefinery Partnership
Algal Biofuel Baseline Technoeconomics
Sustainable Algal Biofuels Consortium
DOE "Idea" Program

AFOSR Bio-jet Program

Microalgal Biofuels TEA

International Algal Biofuels State of Technology Report

NREL's Pursuit of Key Process Components

Compositional Analysis

Feedstock Processing

Feedstock logistics

Biomass Analysis

Lipid yields

Catalyst Development

Algal Biology

Cultivation

Harvest Dewatering

Oil Extraction

Conversion to Fuel

Biomass Fractionation

Co-products

Feedstock Quality and Monitoring

Sustainable Production

Sustainable Harvesting

Feedstock Genetics and Development

NREL Focus for Algal Biofuel R&D

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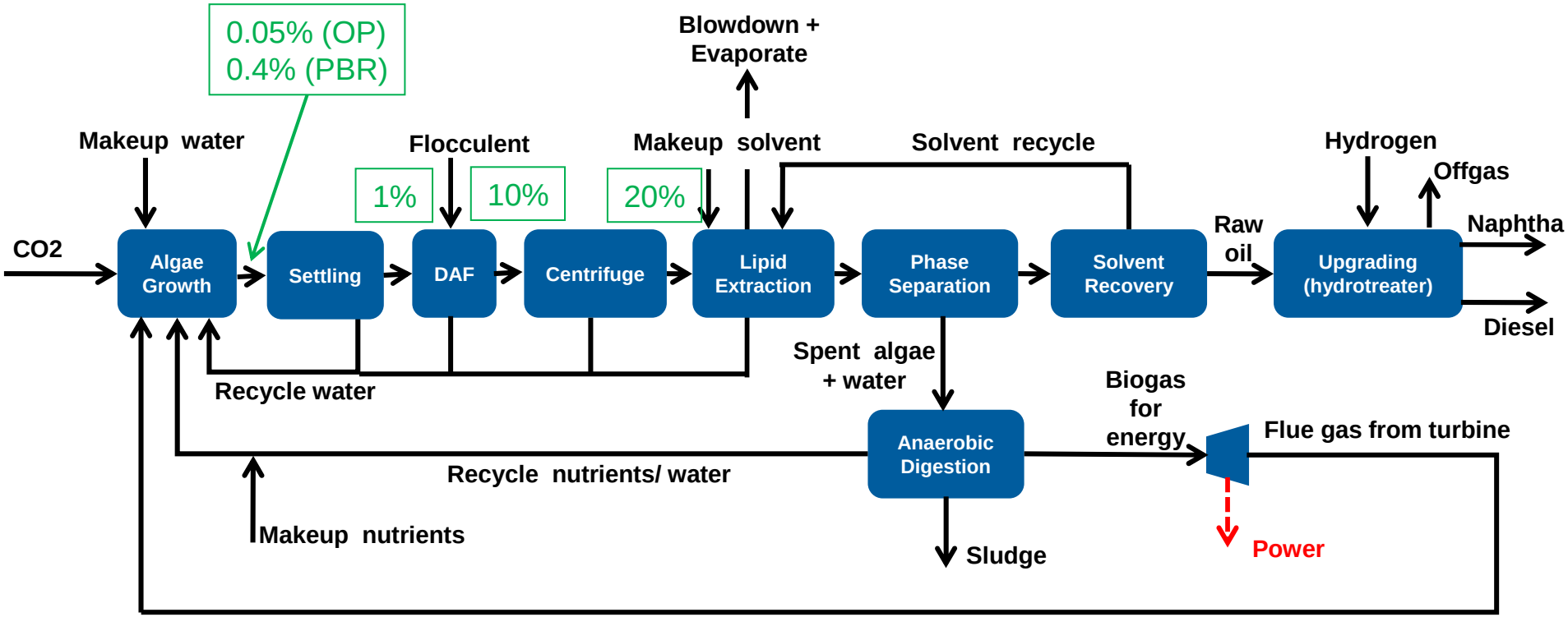
Feedstock Genetics and Development

Technoeconomic Analysis

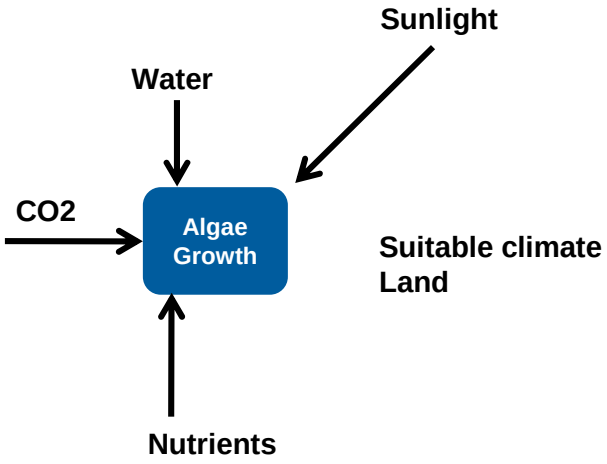
Large Scale Algal Biofuels Process



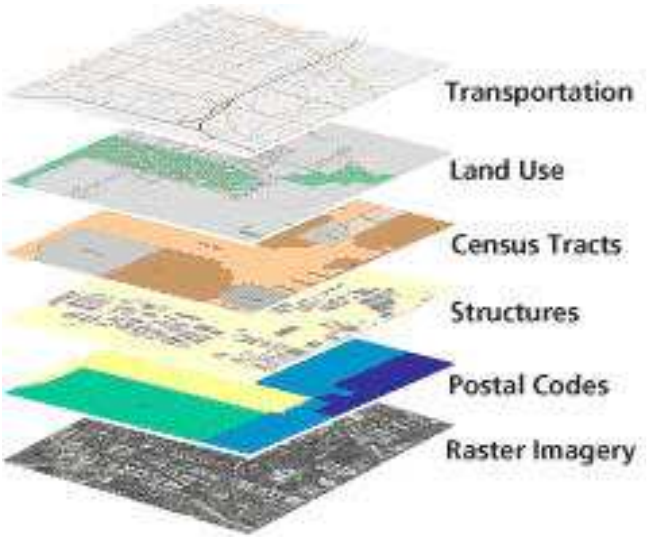
Green = algae cell density

Techno-economic analysis of autotrophic microalgae for fuel production. Ryan Davis, Andy Aden, Philip T. Pienkos. Applied Energy 88:3524–3531(2011).

Algal Resource Requirements



Geographic Information System (GIS):
a computer-based system used to create, manipulate, analyze, and visualize geographic information; GIS allows searching for relationships and patterns,
and perform complex analyses in a spatially explicit way.



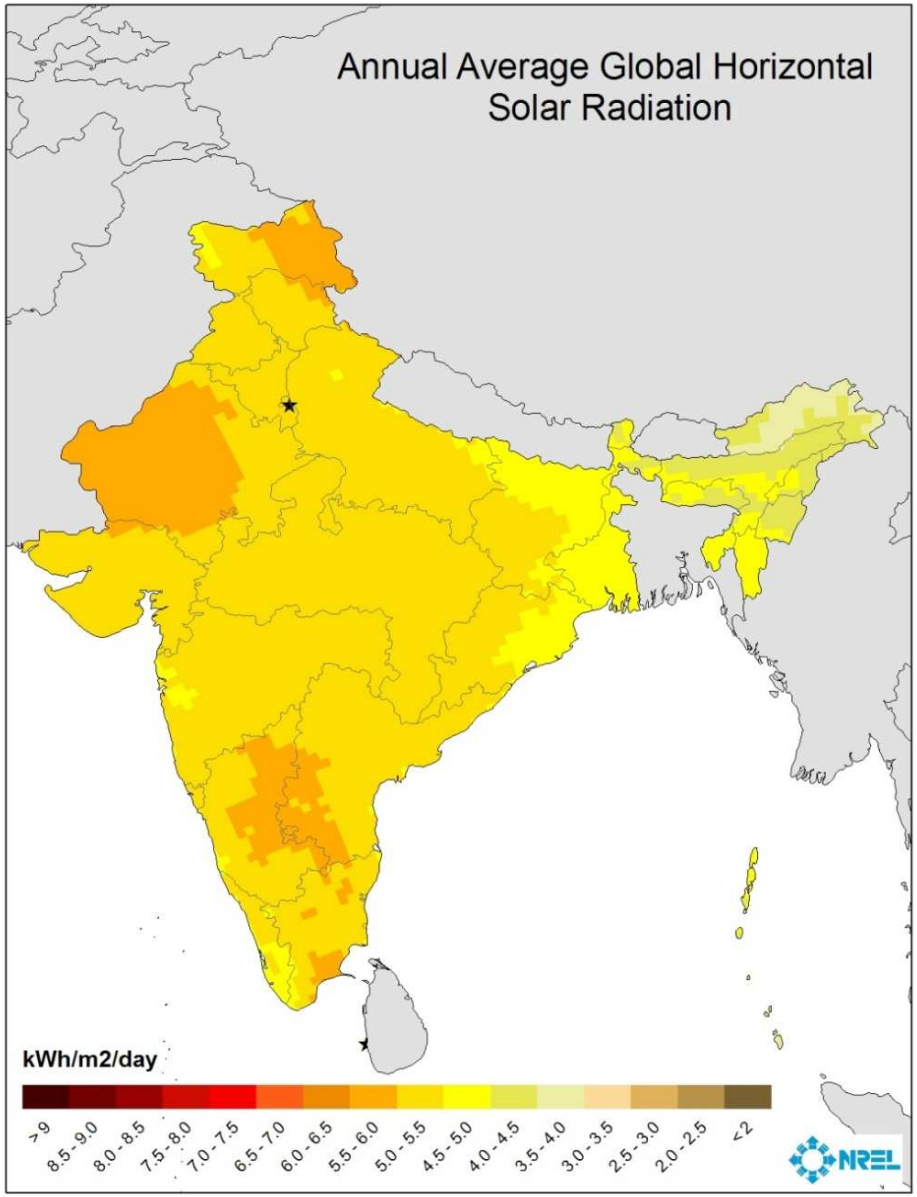
Objectives of India Resource Study

1. Examine the resources available for algae production in India:
   - Climate
   - Water
   - CO_2 and other nutrients
   - Land
2. Identify areas suitable for algae production:
   - *Co-located algae farms,* which produce algal biomass in conjunction with another process
   - *Dedicated algae farms* with the main purpose of algae production

Climate Considerations

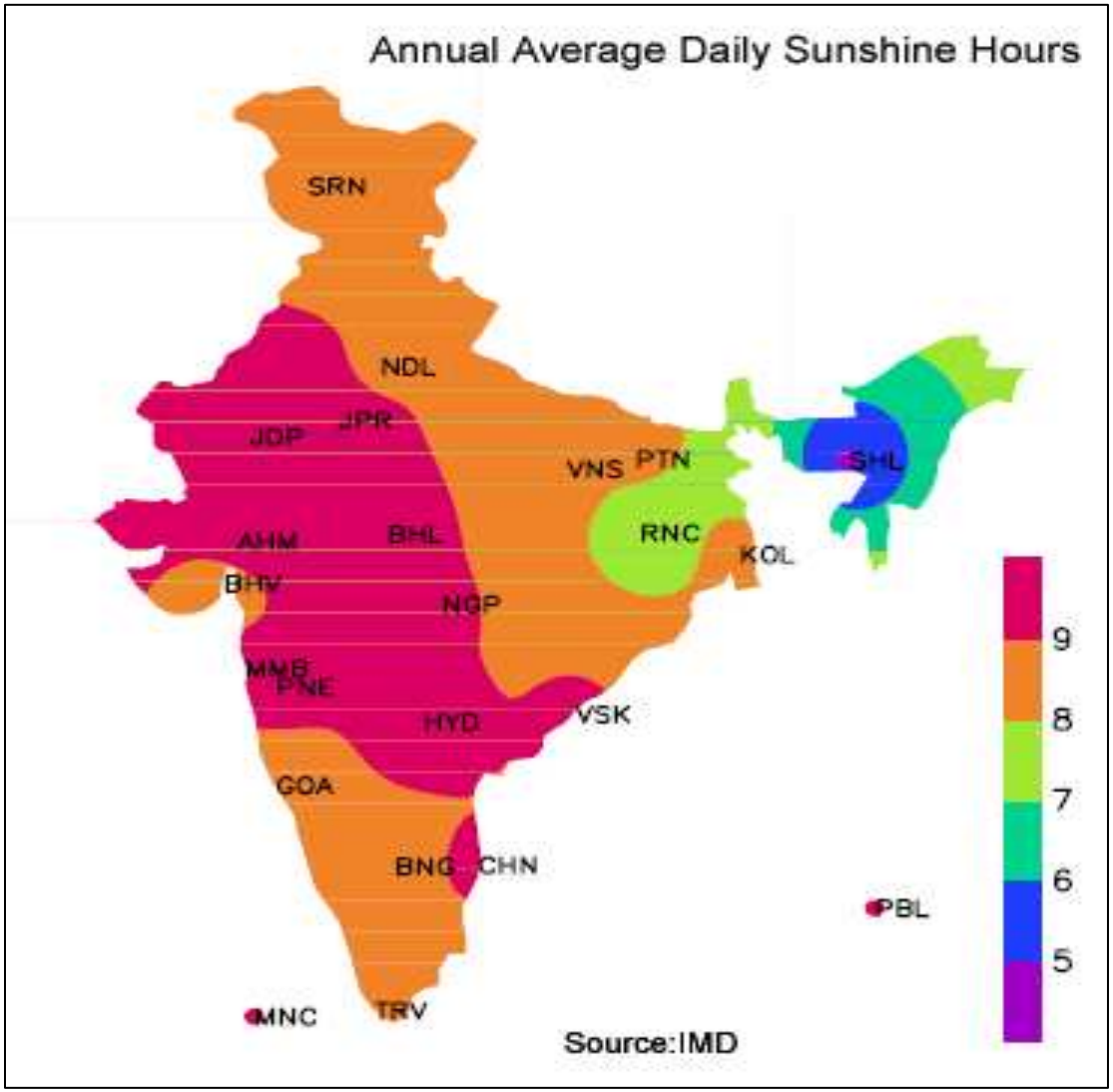
- Solar radiation
- Sunshine hours per day
- Temperature
- Precipitation
- Evaporation
- Severe weather

Climate…Solar Radiation



- >4.0kWh/m²/day annual average considered adequate for algae production
- Almost entire country except parts of the northeast gets adequate solar energy

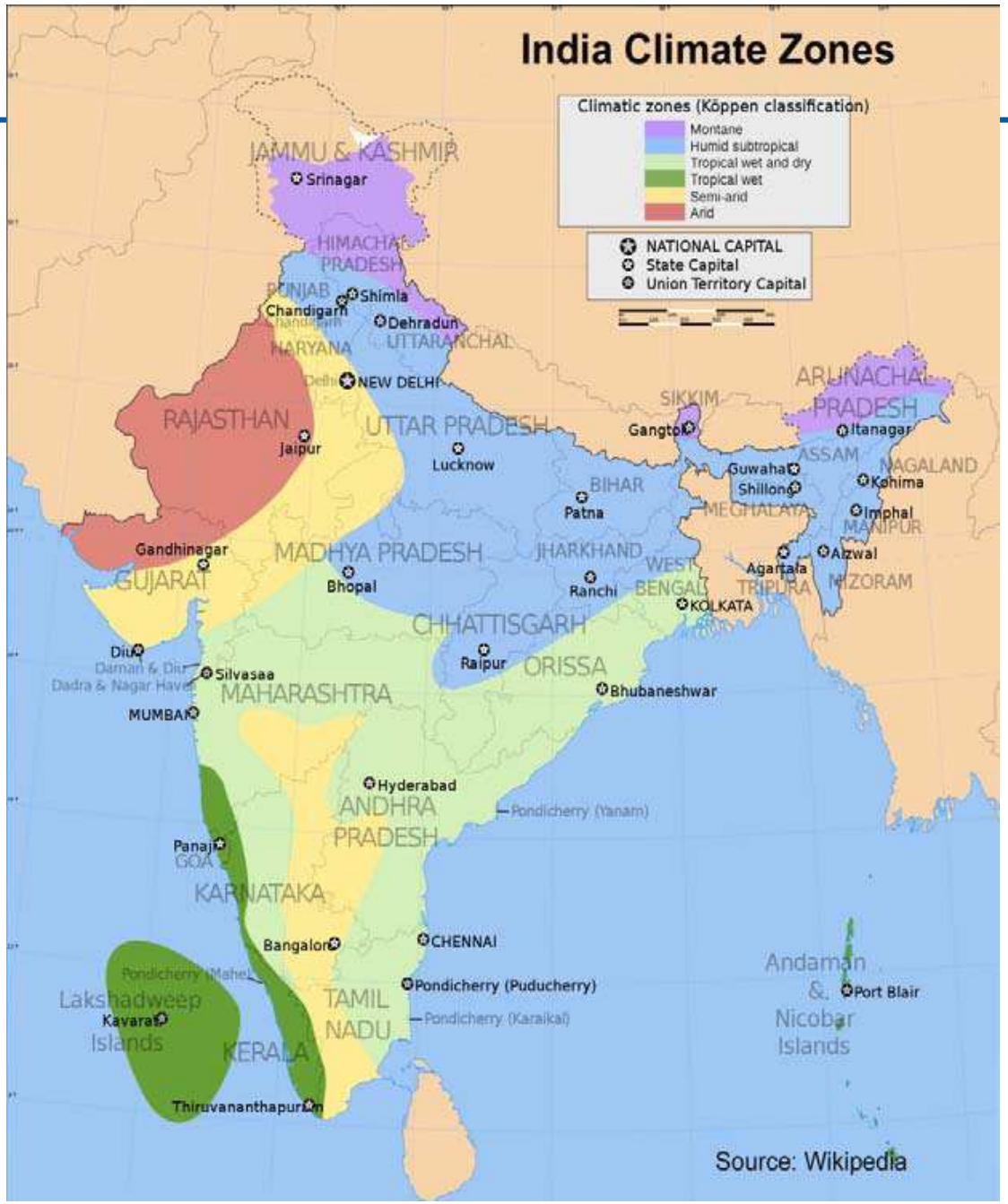
Climate…Solar Radiation



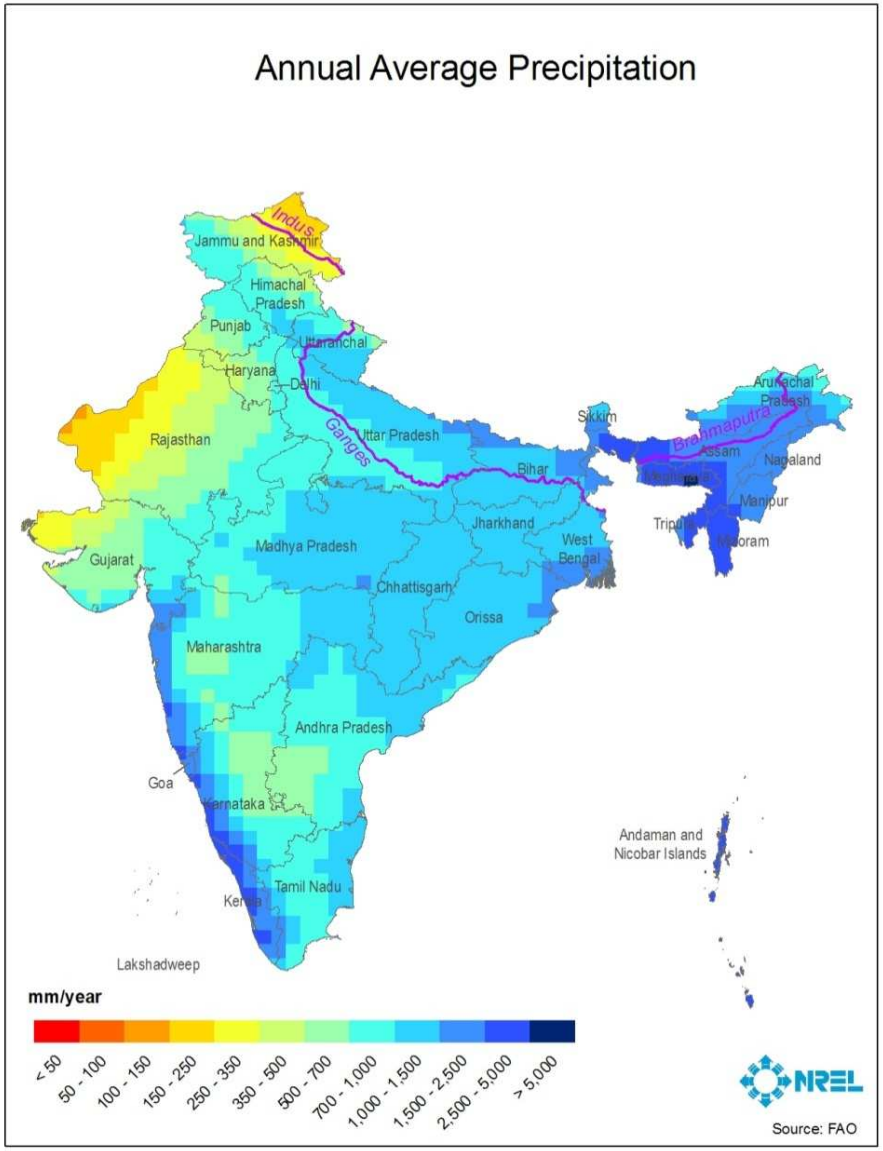
- Ranges from <5 hrs to >9 hrs/day
- <6 hrs/day considered inadequate
- Seasonality: monsoon season (mid-June through September) has lowest number of daily sunshine hours

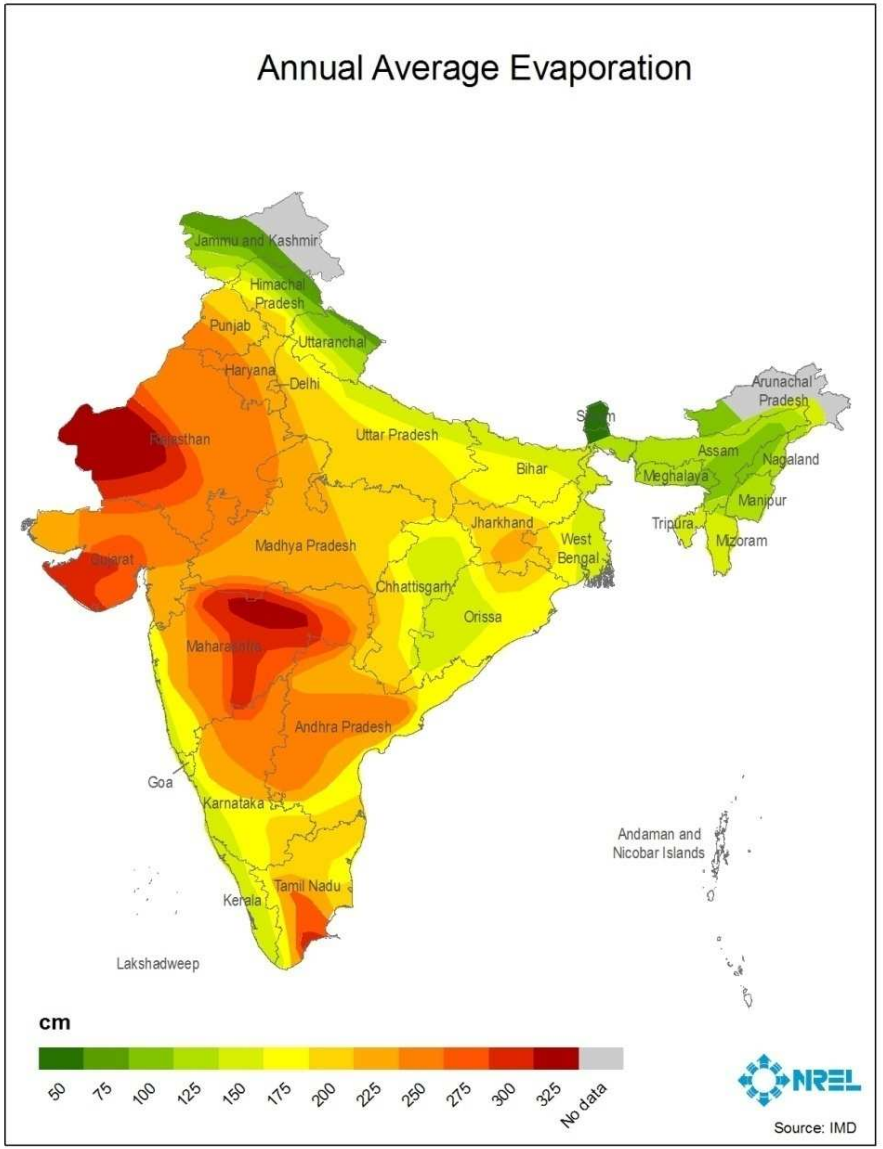
Climate Zones

- Range of climate zones from tropical to arid to mountainous
- Generally warm temperatures
- Temperature only restricts algae opportunities in northern and eastern mountain regions where freezing becomes an issue



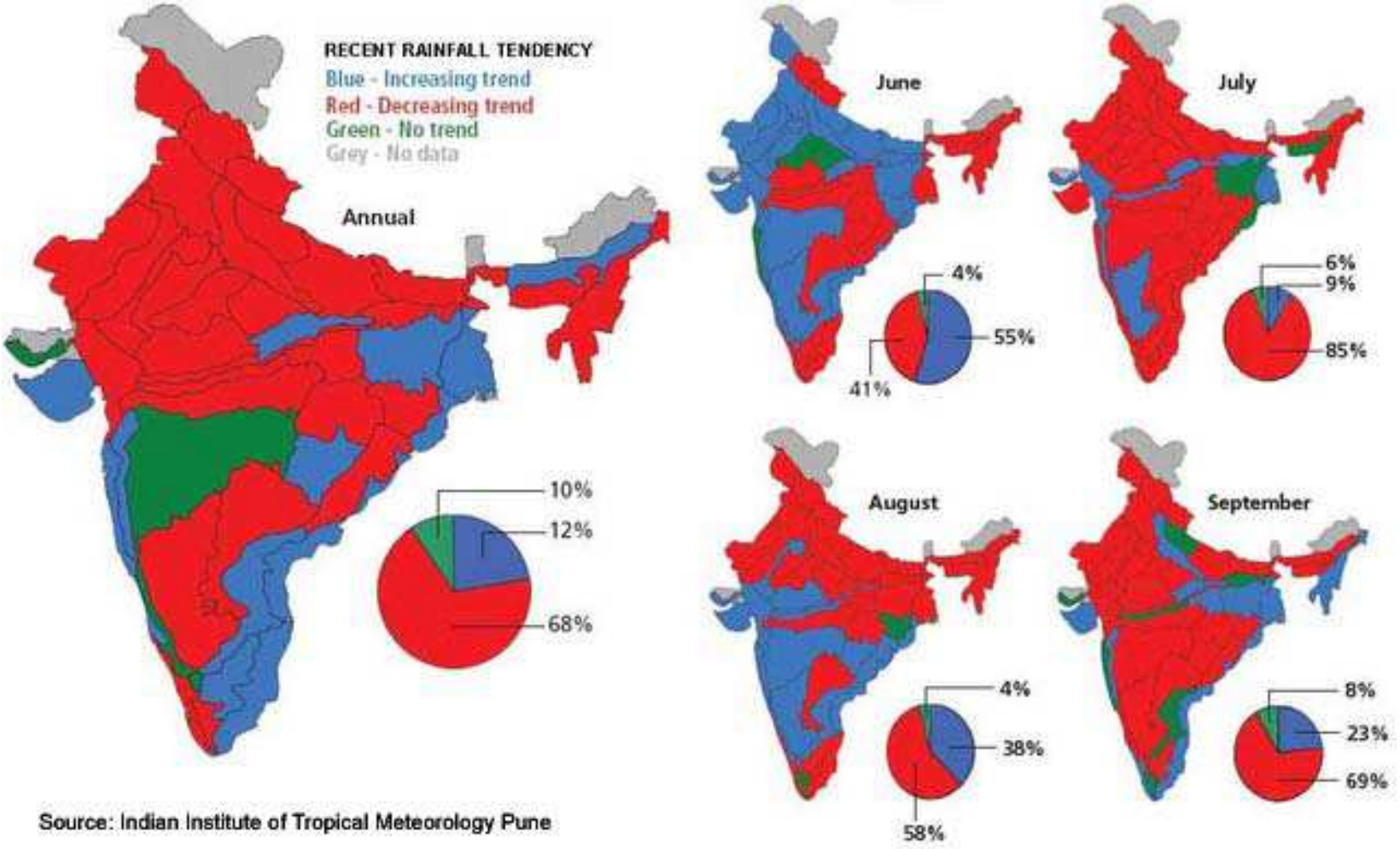
Climate…Rainfall and Evaporation





Climate…Rainfall Trends

Rainfall Trends, 1813-2006

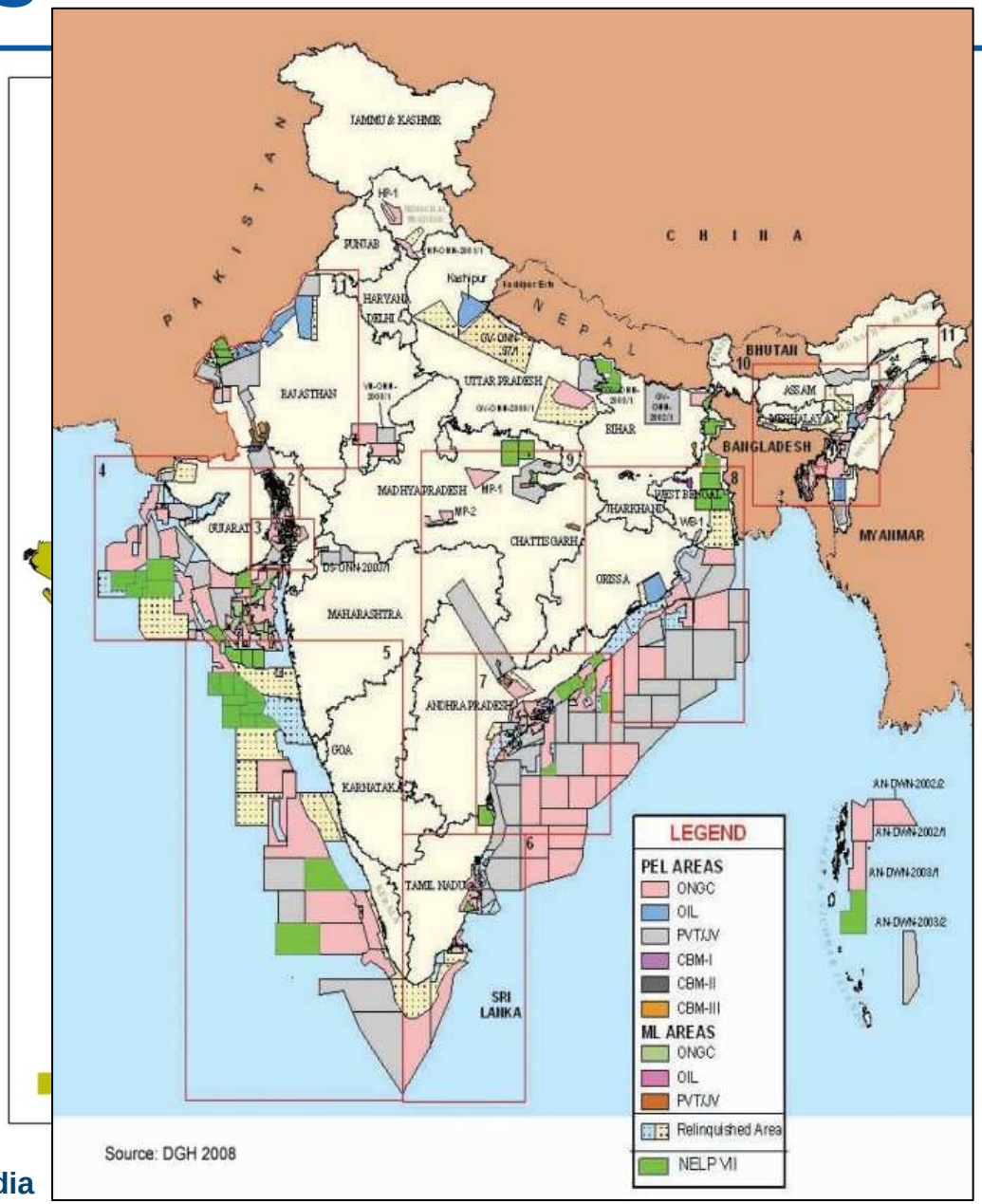


Water Resources

Surface (rivers) and groundwater sources

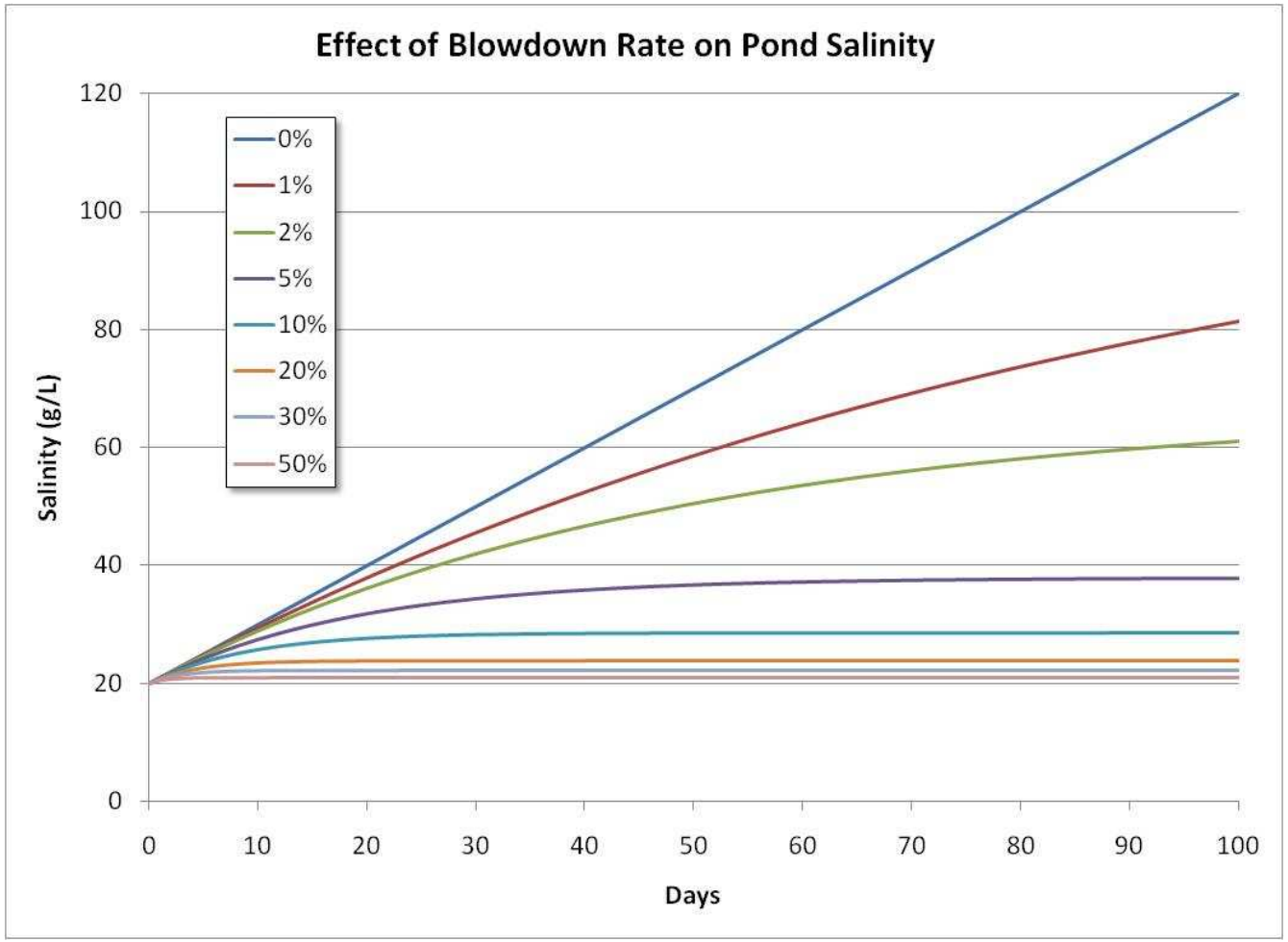
Algae can utilize water with few competing uses:

- saline and brackish water
- “co-produced” water from oil and natural gas wells



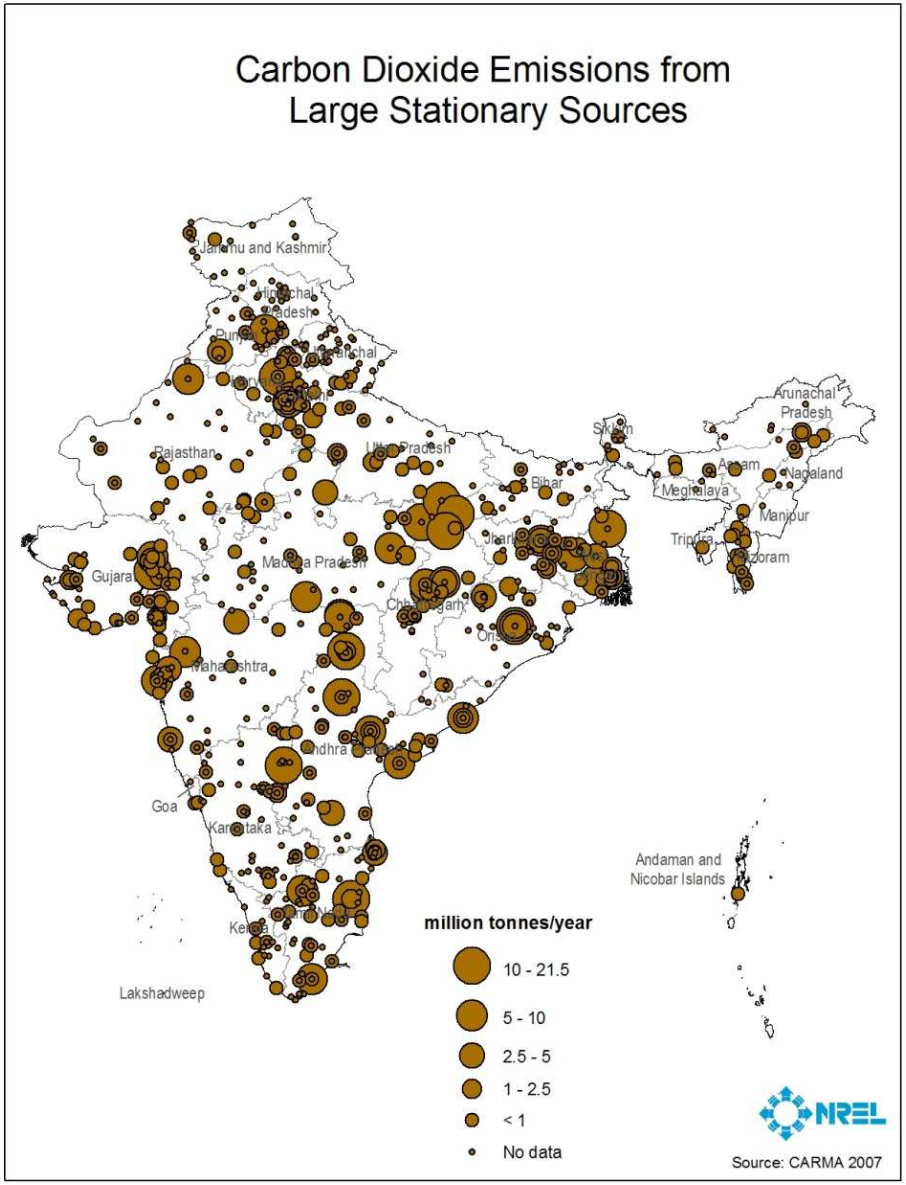
Oil and Gas Fields in India

Freshwater Usage Need Not Be An Issue



Change debate from freshwater usage to brine disposal

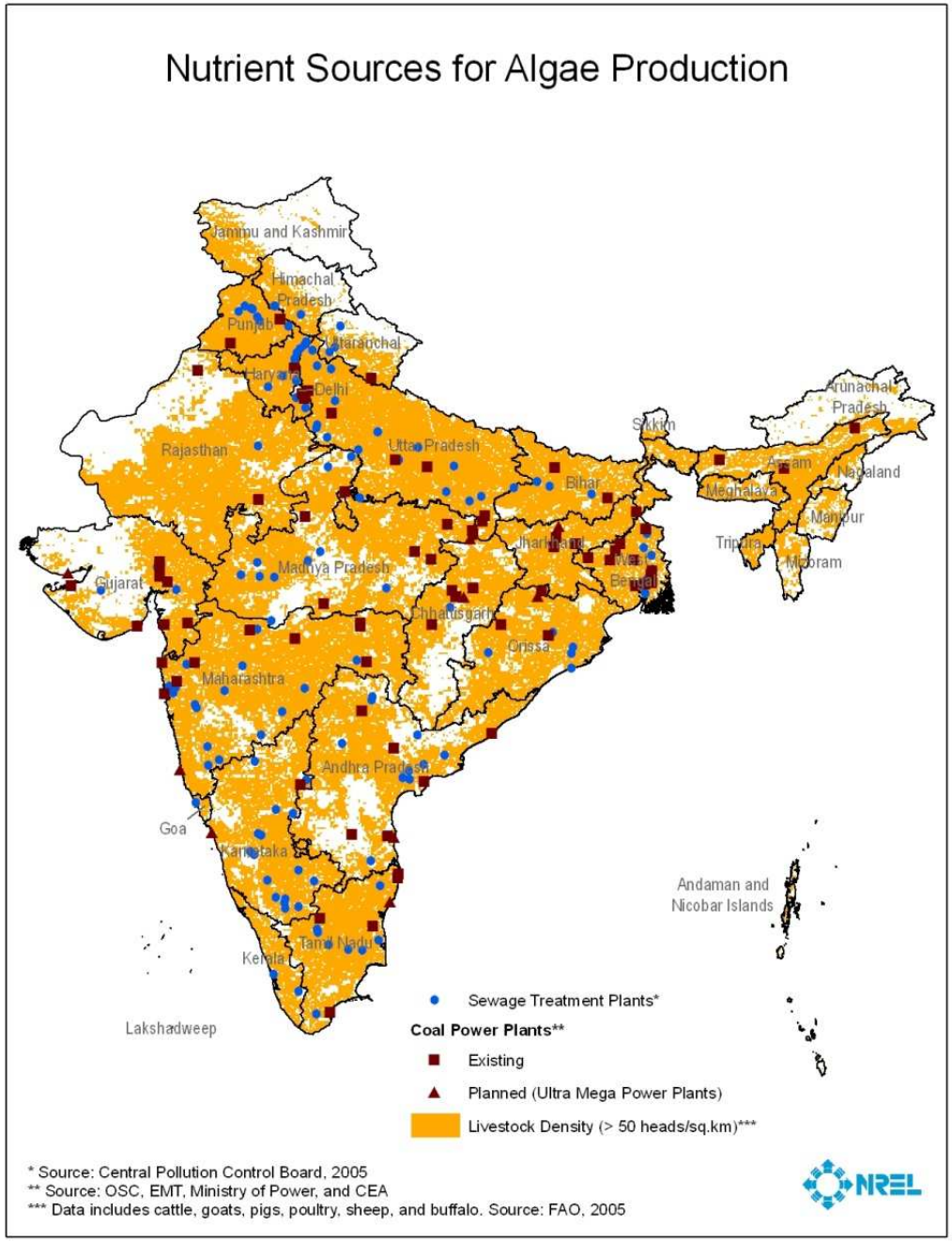
Carbon Dioxide



- CO_2 supplementation required for productive growth
- Large stationary CO_2 sources distributed throughout India (thermal power plants, steel plants, cement plants, fertilizer plants, refineries, and petrochemical plants)
- 638 Mt of CO_2 released into the atmosphere from large stationary sources
- Capturing ~20% would displace 30% of diesel fuel currently used in India

Nutrients

- Nitrogen and phosphorous are key, additional nutrients required
- Co-location with wastewater facilities could provide nitrogen and phosphorous
  - Sewage treatment plants
  - Livestock waste
- Remediation of waste streams could substantially cover costs in co-located facilities

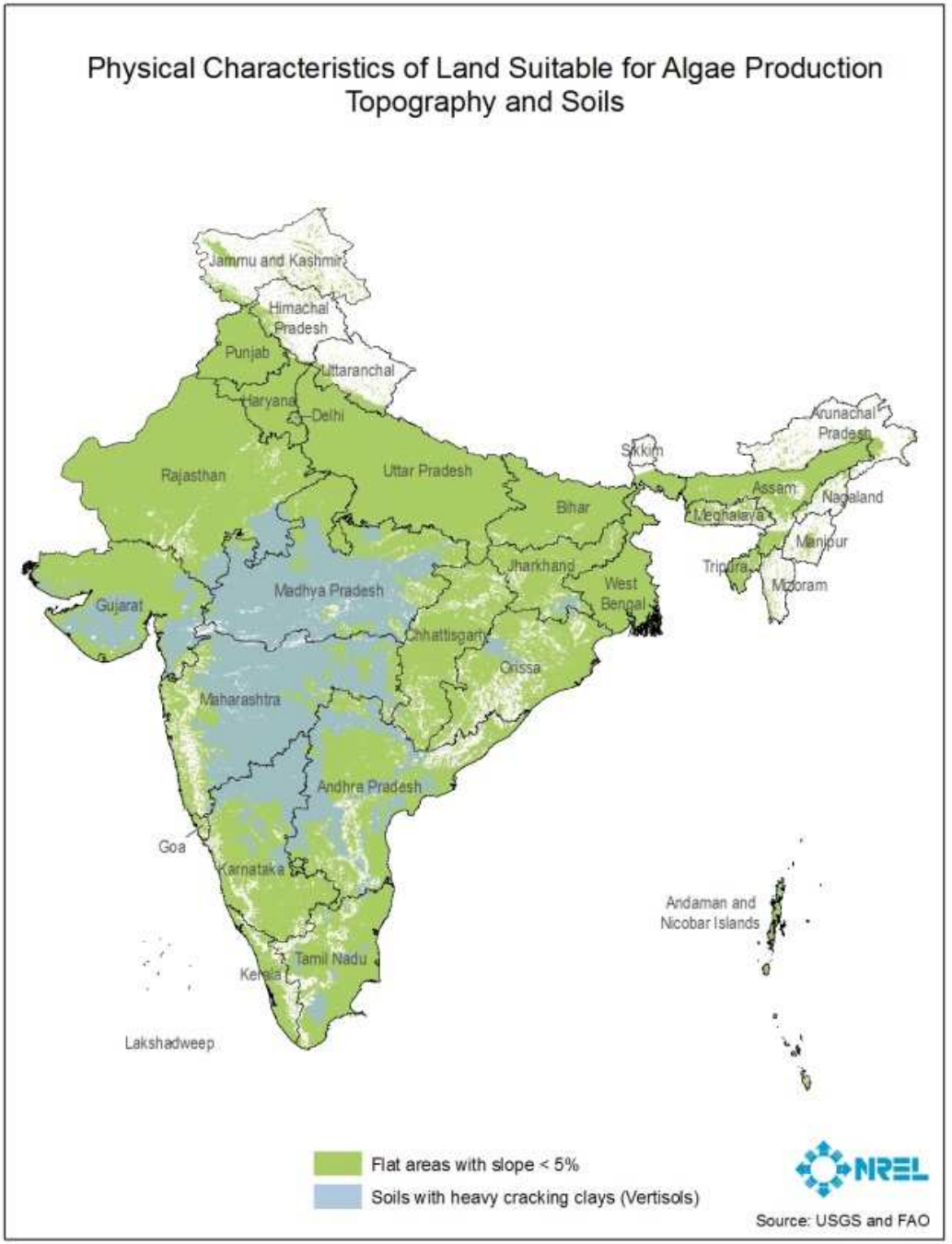


Land Availability

Land Issues:

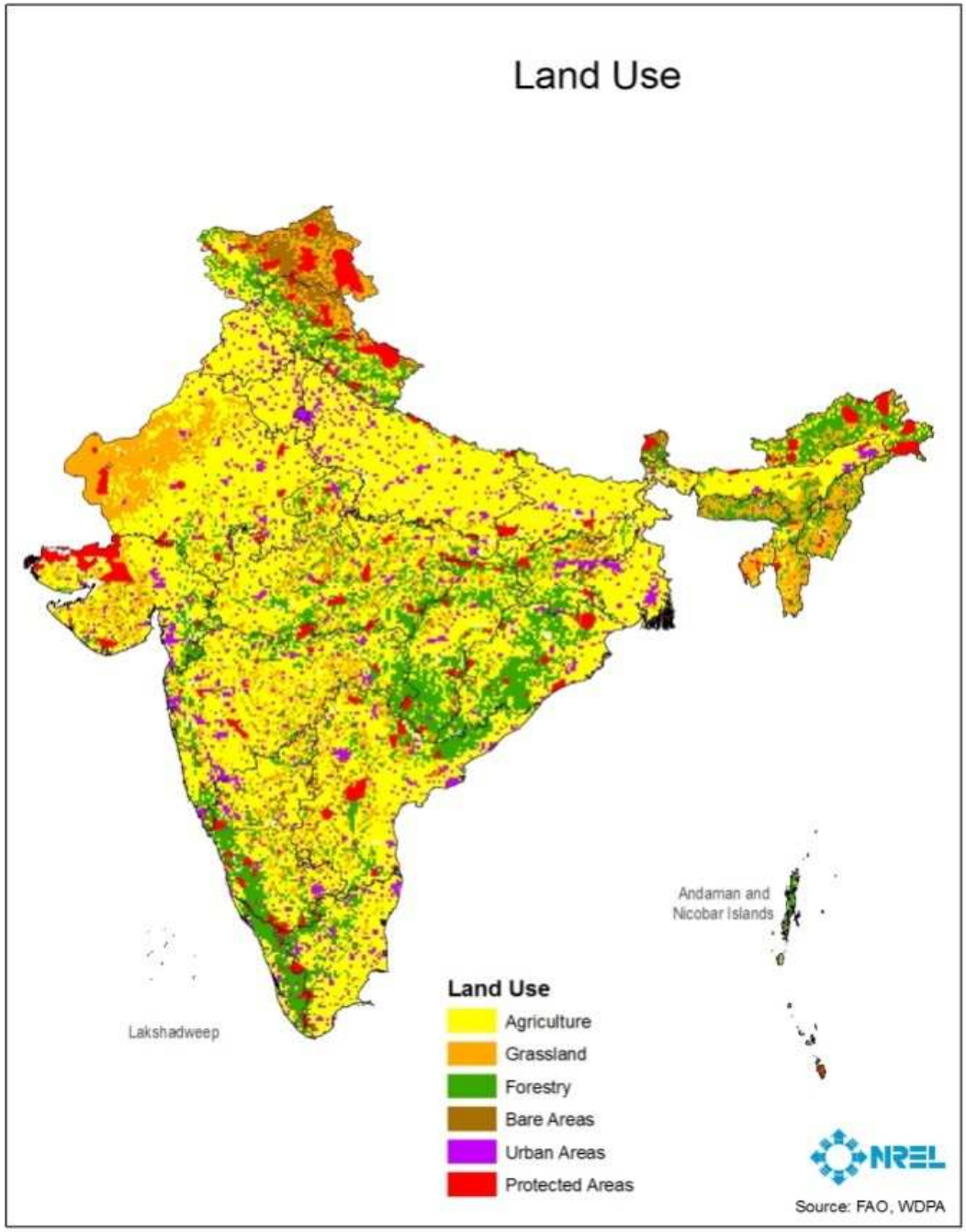
- Physical Characteristics (topography and soil)
- Land Use/Cover
- Cost
- Land Ownership and Stewardship

  - Much of India meets need for relatively flat land (<5% slope)
  - Much of central India has clay soils suitable for minimizing percolation in un-lined ponds



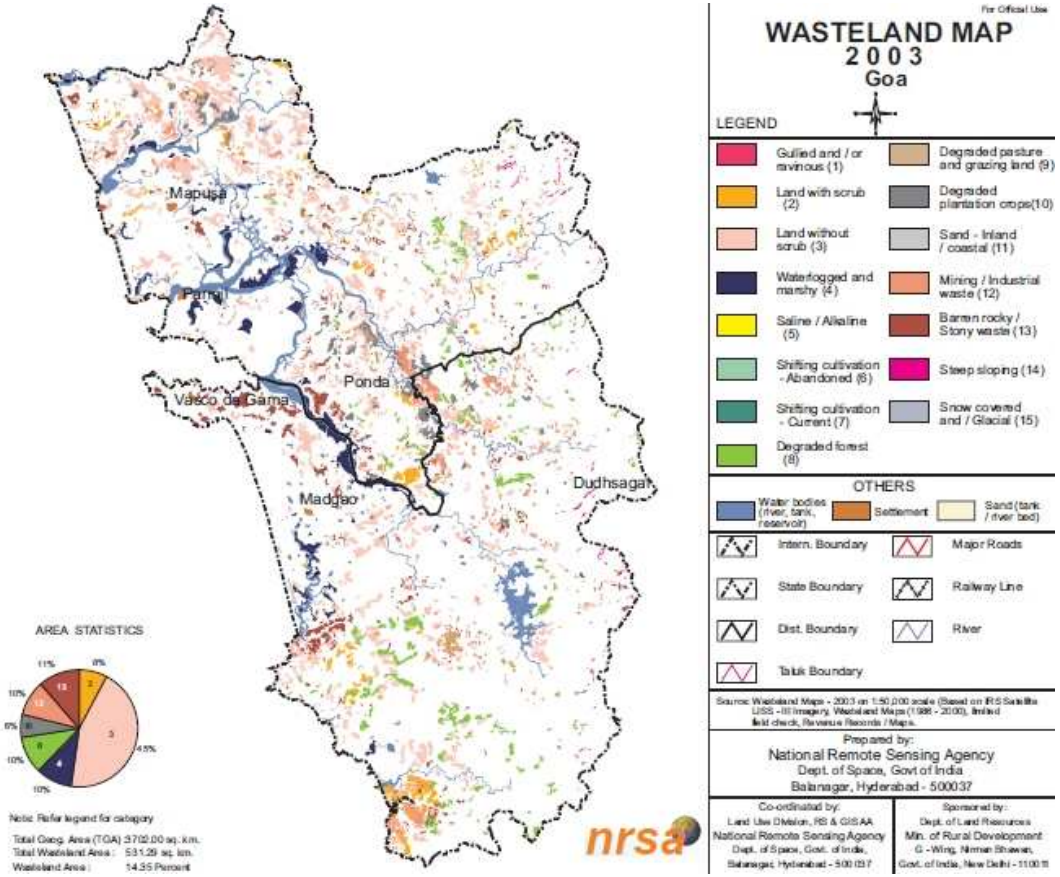
Land Availability

- Productive agricultural and forest lands not suitable (food *vs*. fuel)
- Protected and environmentally or culturally sensitive areas also eliminated
- Agricultural land ~60% of India
- However, some of the agricultural lands shown in the map are degraded and can be considered wasteland



Wasteland

- Include degraded cropland and pasture/grazing land as well as degraded forest, industrial/mining wastelands, and sandy/rocky/bare areas
- Detailed data available* on state-by-state basis
- Extent of these lands is about 55 Mha (approximately 17% of total land area).



*Ministry of Rural Development's Department of Land Resources and the National Remote Sensing Agency (MRD-NRSA 2005).

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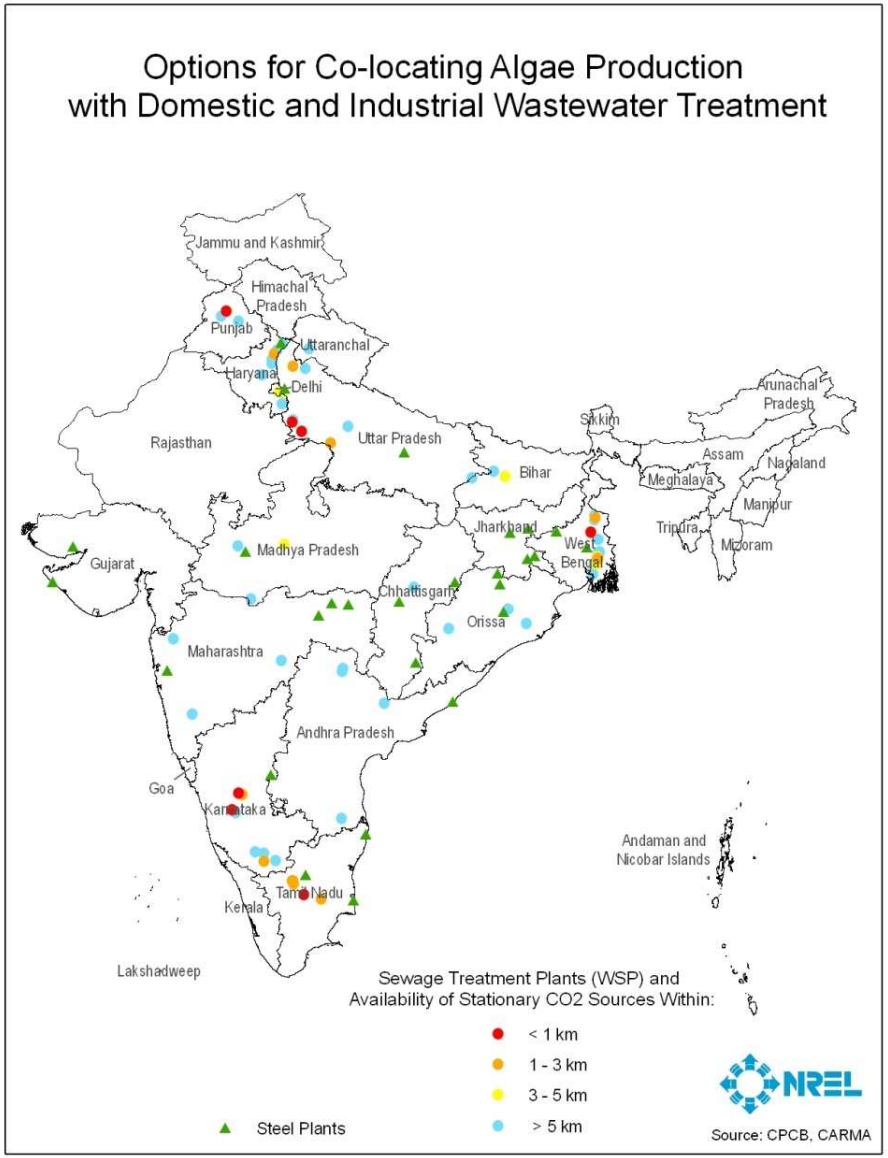
Site-Suitability Analysis for *Co-Located* Facilities

- Operate in conjunction with wastewater treatment where algae are produced as a byproduct of the wastewater treatment process
- Waste Stabilization Ponds (WSP)
- In the near-term, considered the "low-hanging fruit" of algal biofuels
- Using the wastewater effluent as pond medium provides a cost-effective solution to water, land and nutrients considerations, because the wastewater treatment function could cover much of the cost

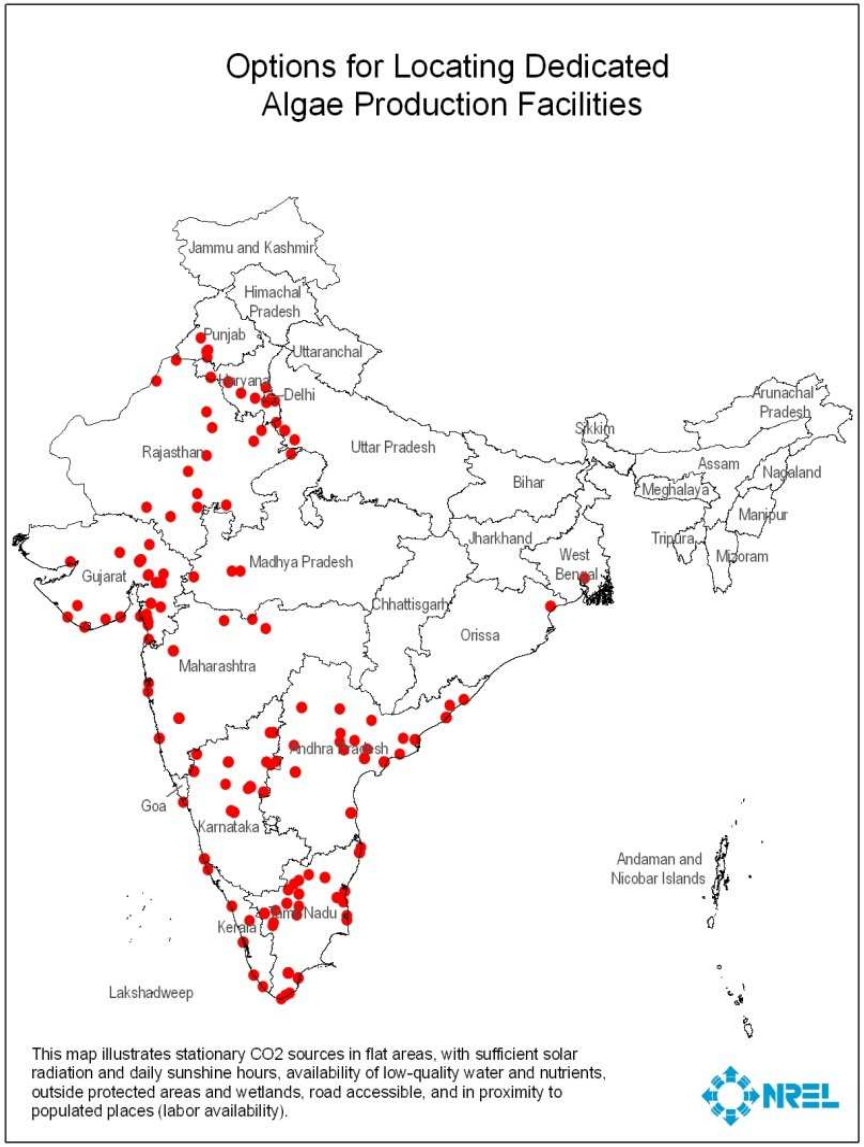


Site-Suitability Analysis for *Dedicated* Algae Farms

All locations

Suitable locations for dedicated algae farms

1. All stationary CO_2 sources
2. Select CO_2 sources with large surrounding area on flat lands (slope < 5%)
3. Select CO_2 sources with sufficient annual average solar radiation (>4kWh/m2/day)
4. Select CO_2 sources with at least 6 hours of annual average daily sunshine
5. Select CO_2 sources in areas with brackish/saline groundwater and along coastal areas (within 10km)
6. Select CO_2 sources with close nutrients availability: 5km of sewage treatment plants and in an area with livestock production >75 heads/sq.km
7. Lands outside protected areas and wetlands
8. Road accessible/labor proximity



Key Findings

Very favorable climate conditions

Most of the country meets the climate requirements for growing algae: sufficient solar radiation, sunshine hours, and warm temperatures

Large volume of low-quality water

Although information on the quantity of low-quality water resources in India is not available, the intensity of activities associated with their production suggests a vast potential

Sufficient CO_2 and nutrient sources

Many stationary CO_2 sources are scattered throughout the country providing opportunities for co-locating algae farms; human and animal organic wastes are available as sources of nitrogen and phosphorous

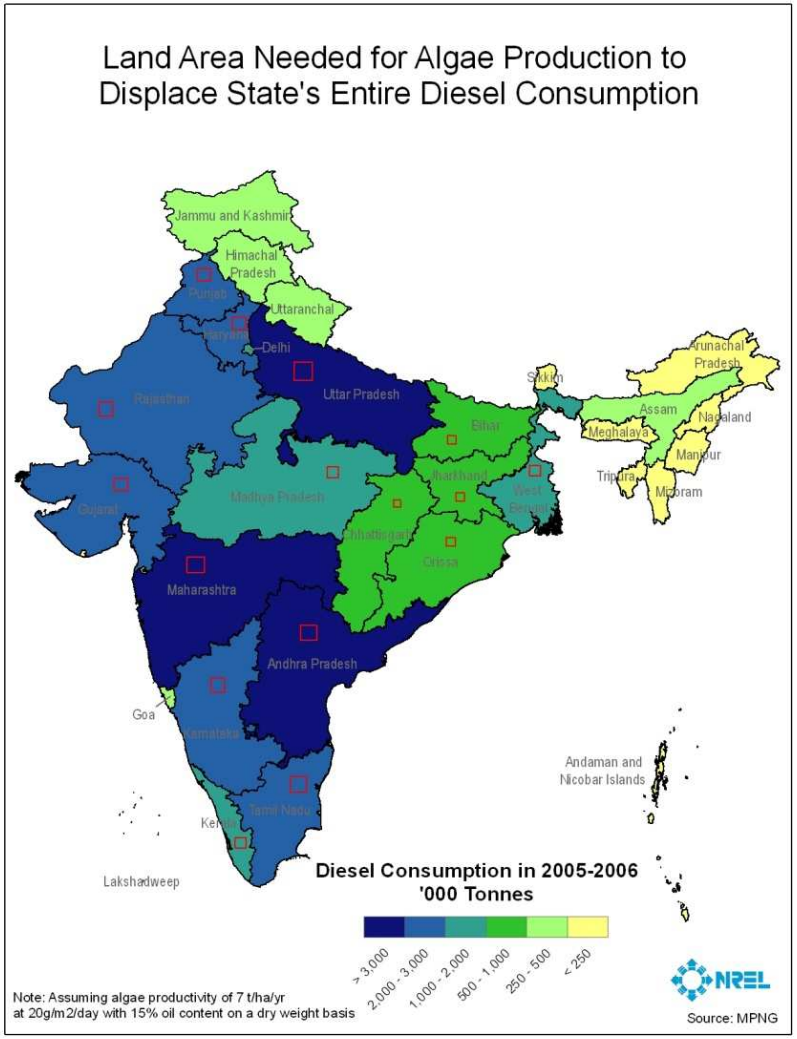
Key Findings (Cont.)

Vast wasteland (about 17% of total land area)

- If India dedicates only 10% (5.5 Mha or 13.6 Ma) of its wasteland to algae production, it could displace 45-100% of current diesel consumption and offset 26-67% of current CO_2 emissions from stationary sources.*

Algae production would have a relatively small footprint

- To substitute 20% of current diesel consumption, algae production would need about 1-2.6 Mha, while* Jatropha curcas, *another feedstock considered for biodiesel production in the country, with best yield of 1 t/ha/yr would need 10.4 Mha of land.*



*Based on a conservative algal productivity of between 8 and 20g/m^2/day with 15% oil content on a dry weight basis.

Suggested Future Work

- Validate the quality of existing data and gather additional information, such as the location of agricultural runoff collection sites, evaporative ponds used by the oil/gas production and mining industry, as well as other wastewater treatment facilities.

- Collect information on the volume of wastewater.

- Focus on a state or even smaller geographic area to provide a more detailed examination of the resource potential for algae production and pinpoint the most suitable locations.

Acknowledgements

Zia Haq, DOE's Office of Biomass Program

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India Meteorology Department

Directorate General of Hydrocarbons, India Ministry of Petroleum

Thank you!

Resource Evaluation and Site Selection for Microalgae Production in India

http://www.nrel.gov/international/pdfs/48380.pdf

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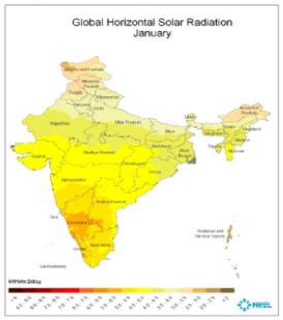
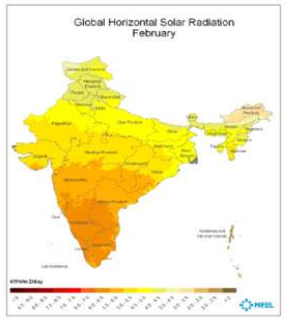
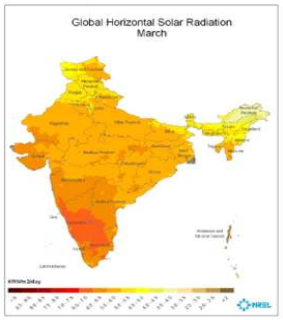
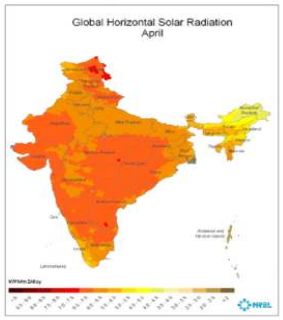
Additional Slides

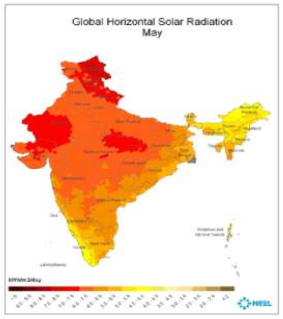
Monthly Average Solar Radiation

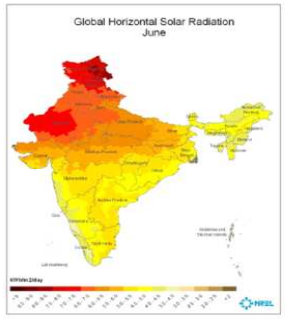


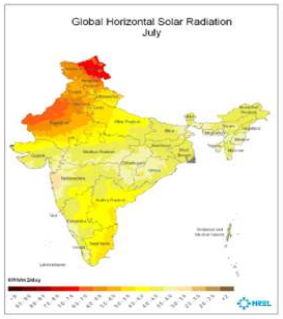


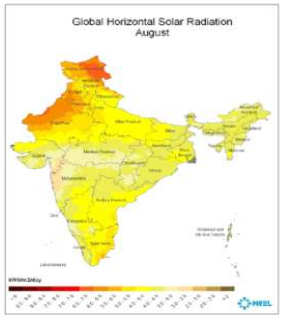


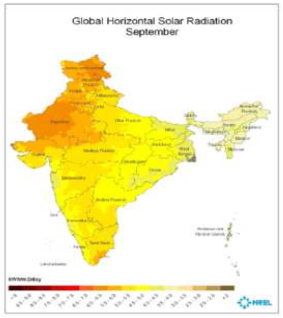


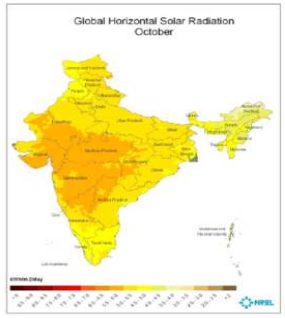


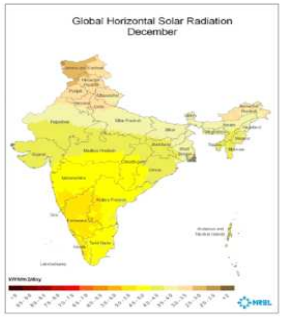




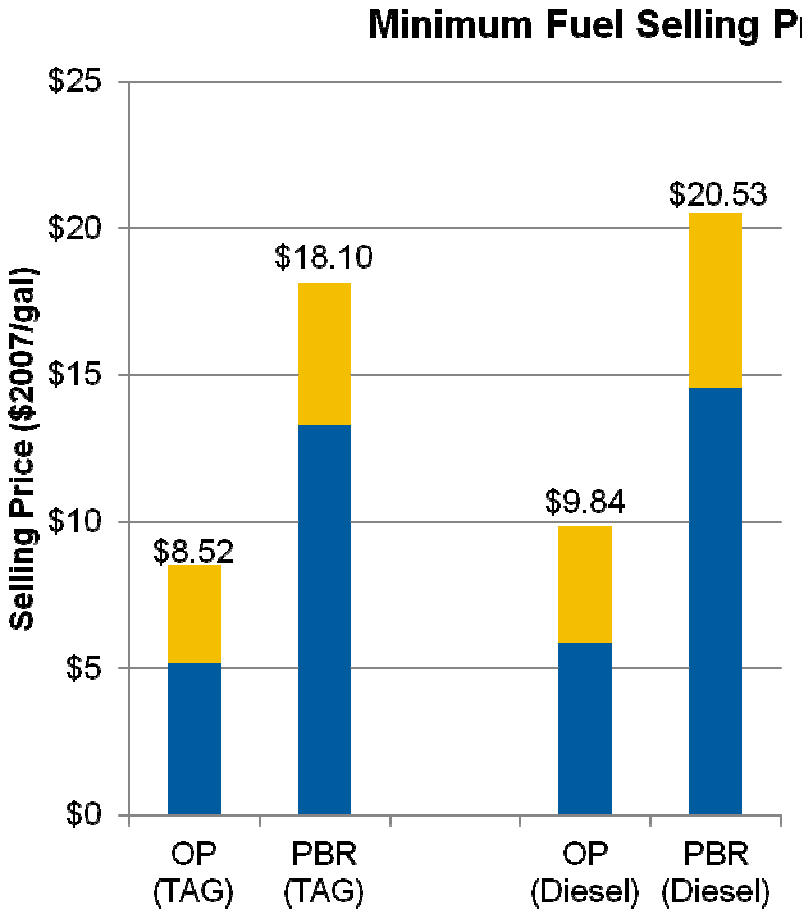


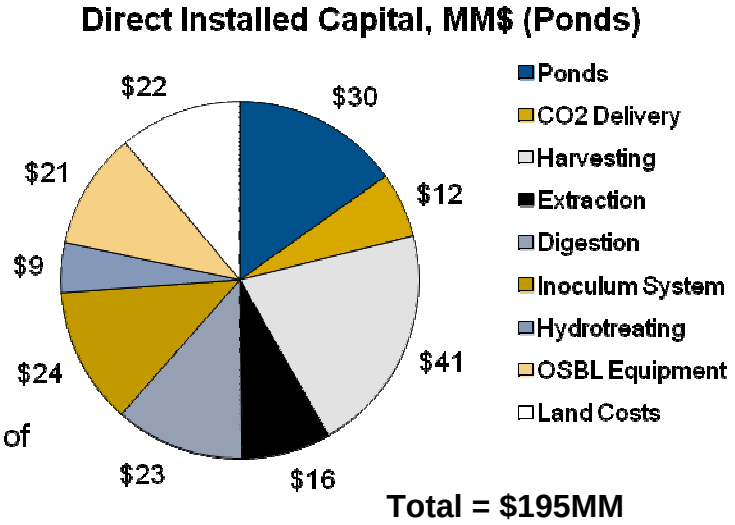


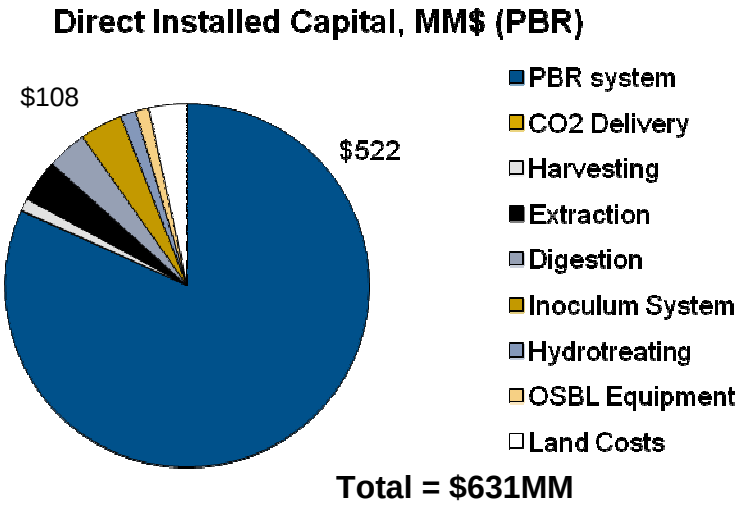




Baseline Cost Results







Baselines show high costs of today's currently available technologies, opportunities for cost reduction

Algal Biomass: A Versatile Feedstock