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Growth is Life

Energy options and scenarios for transitioning to a lower carbon economy: An Indian perspective

Focus on biofuels

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Outline

1. Current energy scenario

2. Bio-based routes to fuels and chemicals
   - Surplus agri-residue to hydrocarbons
   - Jatropha based biodiesel
   - Algae to ethanol and hydrocarbons

3. Summary

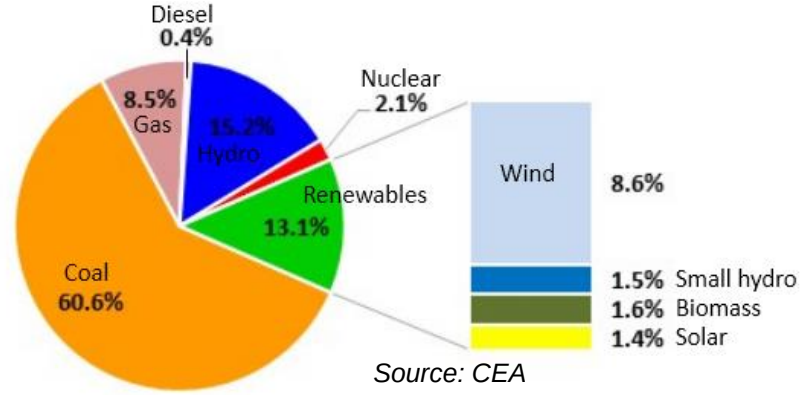
Indian energy scenario

India is 3rd largest energy consumer in the world

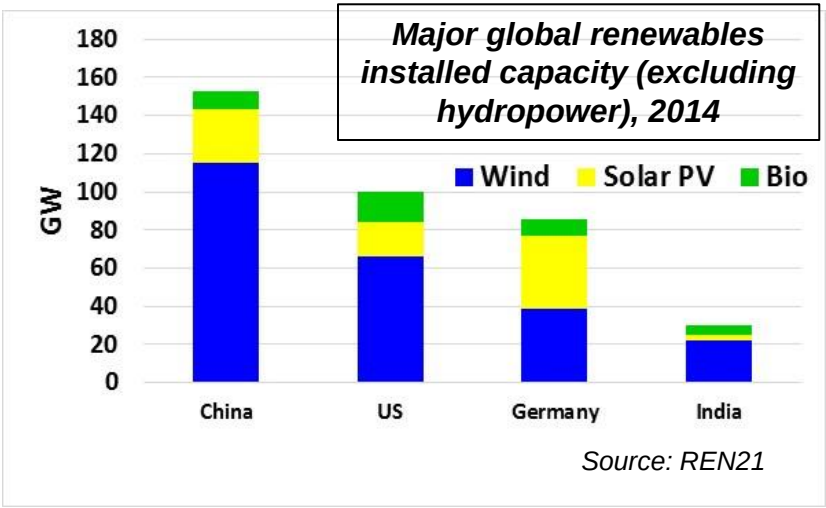
- Annual energy demand expected to increase 200% from FY 15 to FY 30
- Today India imports ~81% crude oil and ~41% natural gas (> $ 70 bn revenue outgo)
- Today India has
  - 0.8 % of World's Gas reserves
  - 0.3 % of World's Oil reserves
  - 6.8% of World's Coal reserves

Country	Per capita CO_2 emissions (metric tons, 2011)
USA	17
Russia	12.6
Japan	9.3
UK	7.1
China	6.7
India	*1.7*
World Average	*5*

Power scenario of India (as on Mar. 2015)



Source: CEA



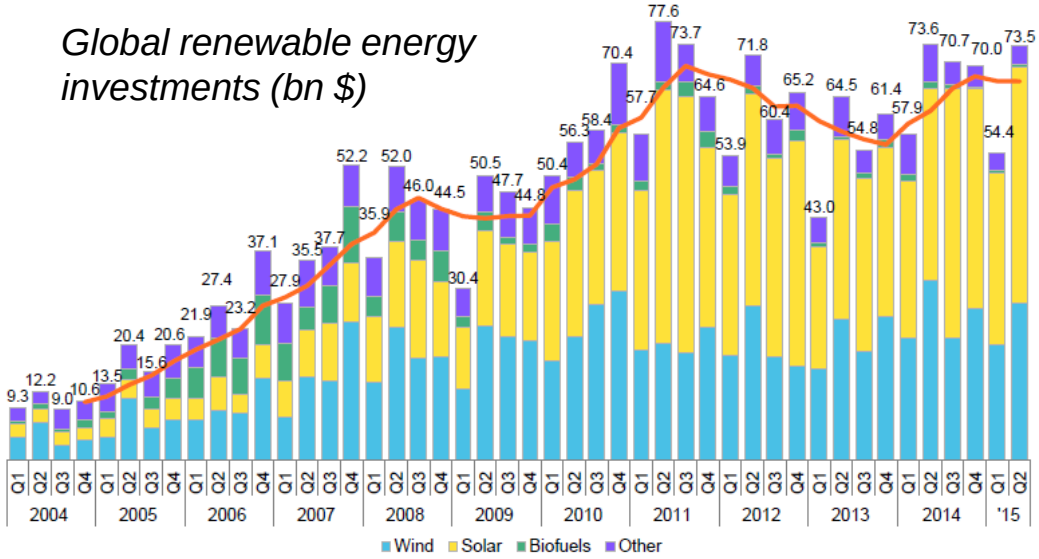
Source: REN21

Total installed capacity = 264 GW as on March 2015
Renewables = 13% of capacity, 7% of electricity produced

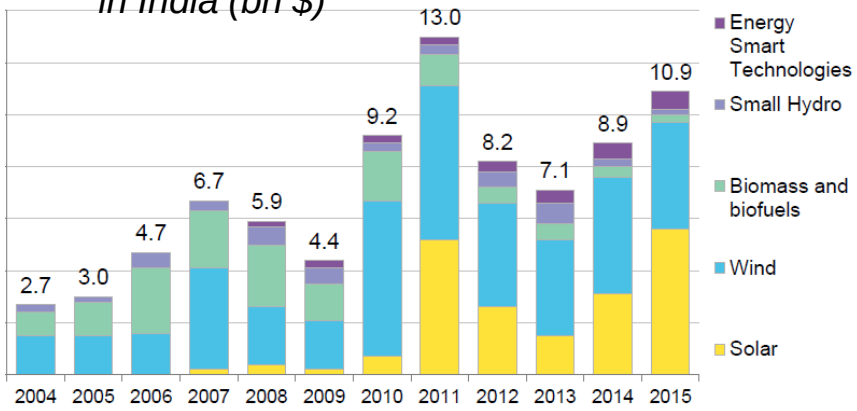
Significant potential to increase contribution from Renewable Energy in India

Global and domestic investments in biofuels lag behind other renewables

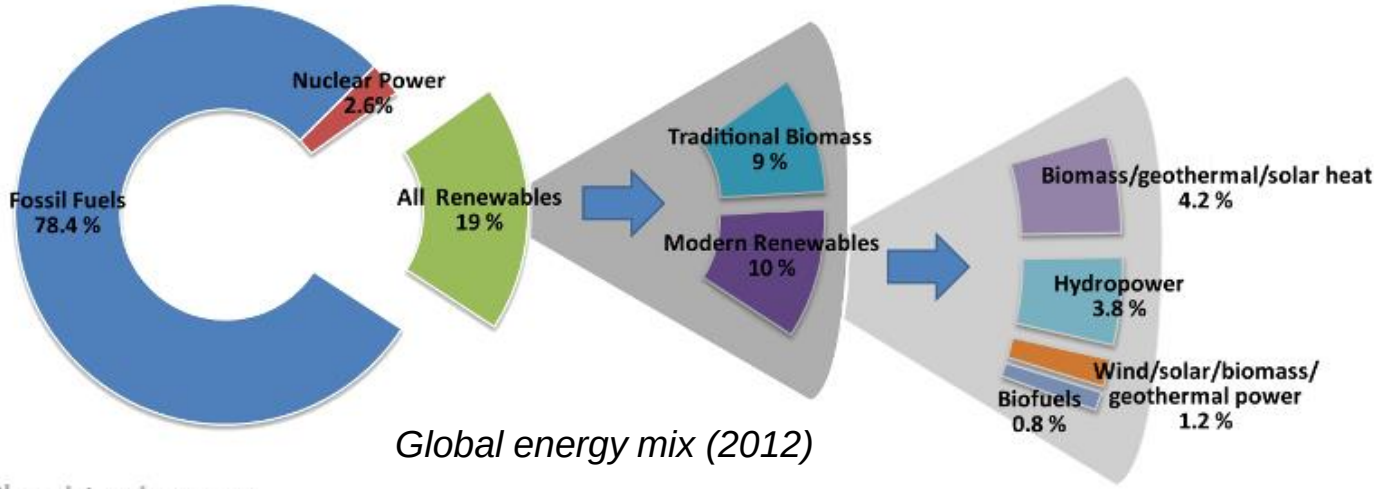
Global renewable energy investments (bn $)



Renewable energy investments in India (bn $)



Source: BNEF



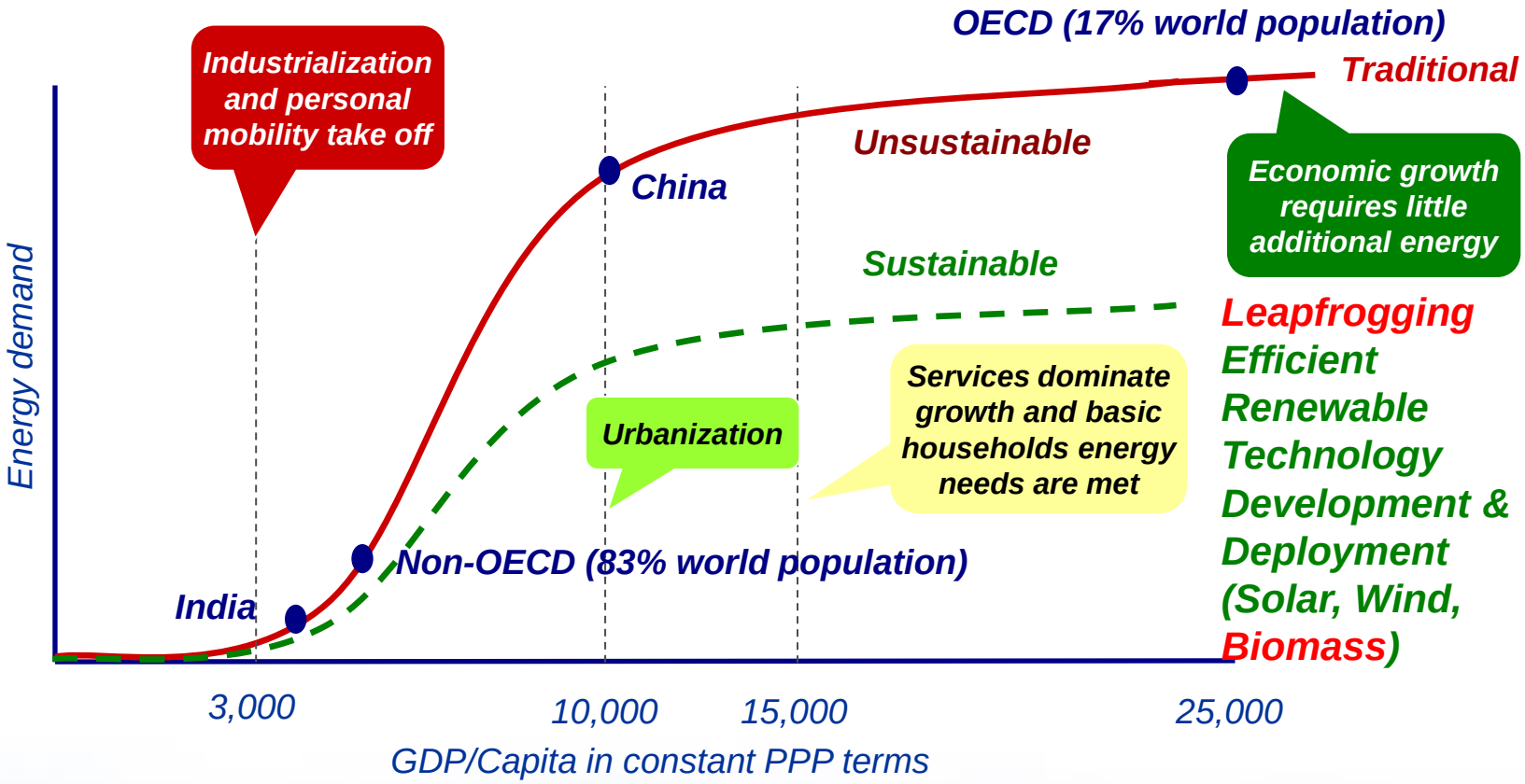
Global energy mix (2012)

Traditional biomass is still a significant fraction of the global energy mix

Biomass can deliver products in the form of hydrocarbons that are easily storable and transportable; it can also create significant rural employment opportunities

Sustainable development challenge

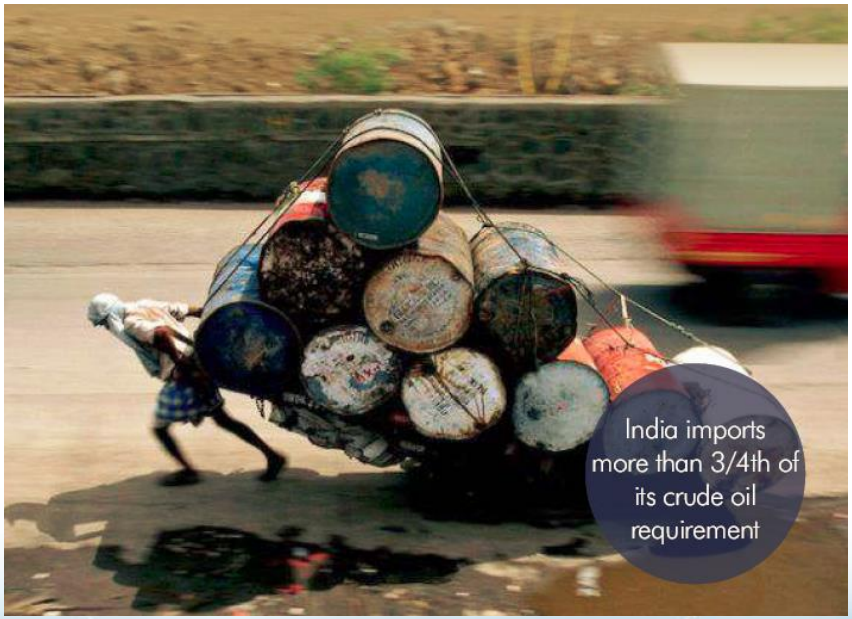
More, Secure and Responsible technology needed for India



Demand for materials & energy is growing rapidly as developing countries like India enter their most energy-intensive phase of economic development

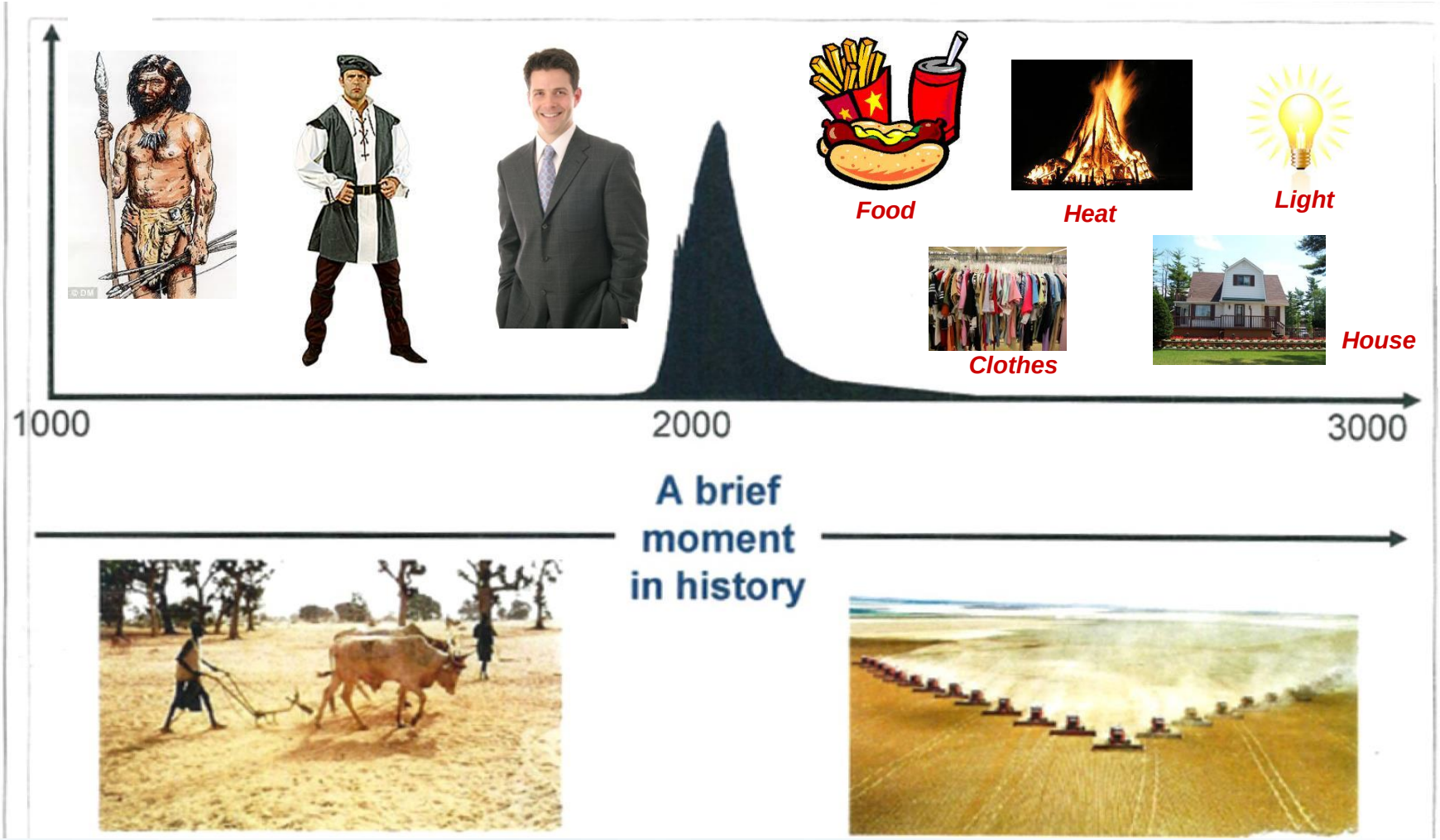
Biofuel drivers for India

- Energy security
- Reduce forex outgo
- Rural upliftment
- Maximum value generation from uncultivable Indian land mass
- No food versus fuel competition
- Climate change mitigation



Bio-fuels key to sustainably meet hydrocarbon demand & improve farmers' livelihood

Future of liquid hydrocarbons?



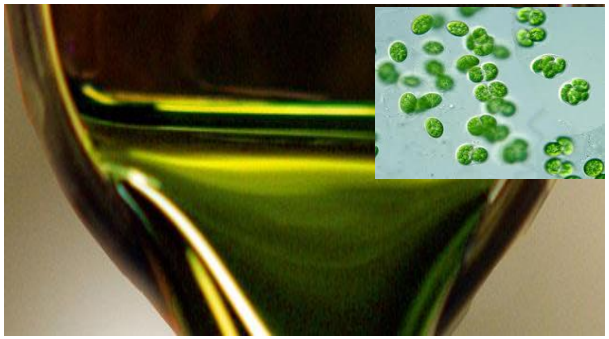
Sustainability & energy security two sides of the same coin

RIL: A significant commitment to renewables R&D, major focus on advanced biotechnology

- Scientists and engineers, trained in the best institutions globally, working in India
- International collaborations with top notch institutions, leveraging talent of additional scientists and engineers
- No food vs. fuel competition
  - Surplus agri-residue (120-150 MMTpa biomass resulting in > 30 MMTpa biofuel)
  - Jatropha (develop high yield varieties in low rainfall marginal land areas)
  - Algae (use sea-water and desert land at coastline)
- Adopt PM's triple S mantra: Skill, Scale and Speed for these challenging problems

Agri-residue to kerosene

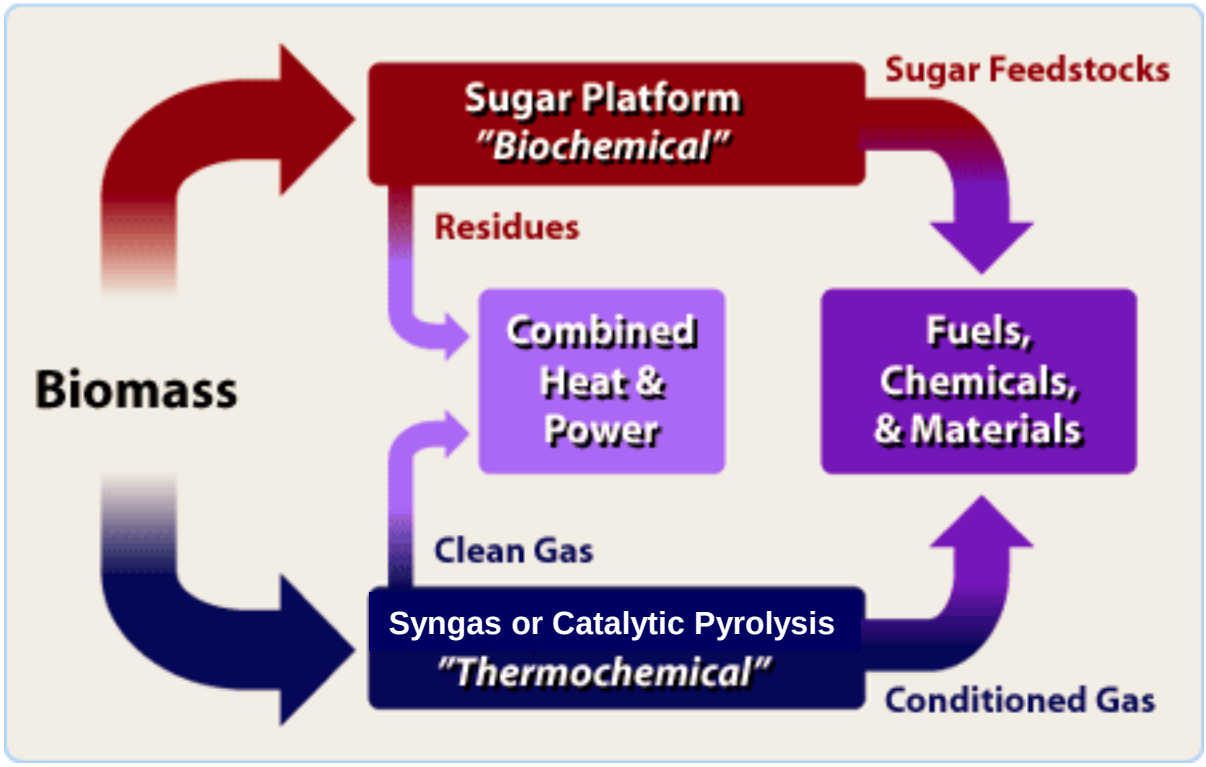
Jatropha to bio-diesel



Algae to bio-crude

RIL committed to largest cutting-edge R&D program by any private enterprise to help India leap-frog

Thermochemical route is economically attractive



- In the Indian context thermochemical routes may be more attractive than cellulosic fermentation due to types of non feed/ fodder bio-mass availability
- Business model innovation: distributed production and consumption at village level

Thermochemical route can improve overall carbon utilization efficiency to end products

Agri-residue conversion to modern energy

Feed Stock	→	Technology	→	De-Construction	Upgrading	→	Product

Agri-residues
Non-fodder/ food-stalks, trash and bagasse

Biomass to Power
1 kg = 1.7 kW
= 1465 kcal

Combined Cycle Biomass Power generation

Power

Biomass to Ethanol
1 kg = 200-250 g =
1420-1780 kcal

Enzymatic Hydrolysis

Fermentation

Ethanol

Biomass to HC Fuel
1 kg = 280 g
= 2960 kcal

Catalytic Pyrolysis

Hydrotreatment

Gasoline/Diesel/Kerosene

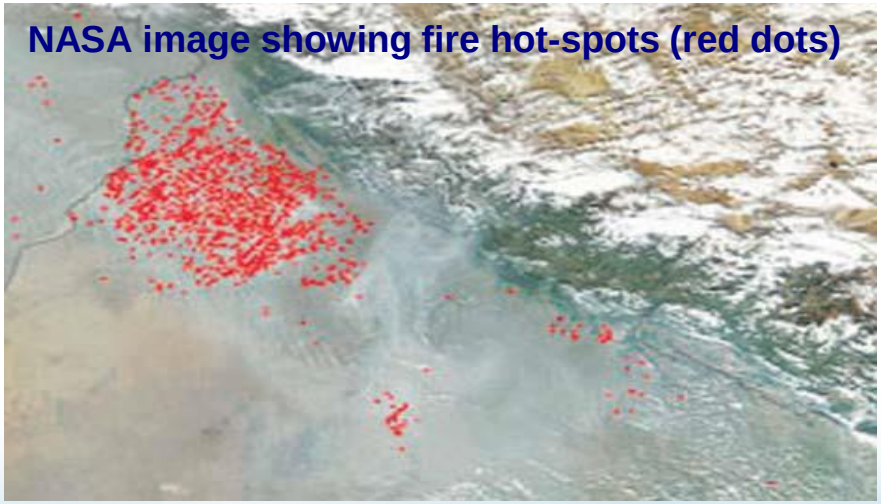
Converting biomass to fungible hydrocarbons like kerosene is more efficient technology

Agri-residue conversion to hydrocarbons more valuable than burning

Burning is a cheap and quick way to clear field but leads to loss of nutrients and pollution

Images from The Guardian

NASA image showing fire hot-spots (red dots)



Source: NASA, Hindustan Times Nov 7, 2013

Pollution in Delhi

Excess agri-residues can be converted to kerosene at village level

Bio-feedstock aggregation/ supply opportunity

Farm Harvesting
Seasonal
Short window
Distributed
Bulky

- *Farm & Farmer Coordination*
- *Manual Labor*
- *Aggregation*

Collection
Moisture, Grits, Foreign Matter, Timing

- *Transport*
- *Weeding*
- *Accounting*
- *Sizing*

Preparation
Loss, Capacity Utilization, Synchronize

- *Drying*
- *Stocking*
- *Planning*
- *Transporting*

- **Biomass surplus 120-150 million tons per annum**
- **Bio-fuels potential > 30 million tons per annum**
- **Collection and processing of biomass is estimated to create additional income stream of at least Rs. 20,000 crore per year for the rural economy**

Innovative business models for supply chain, logistics and cost competitiveness

Oil yield improvement in Jatropha

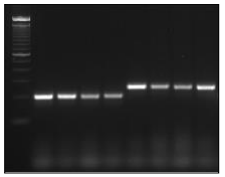
Biodiesel production in India in 2014-15 was only 0.1 MMTPA, a blending level of < 0.2%

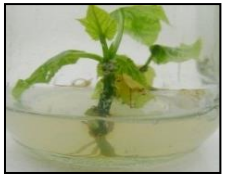
Wild accessions & Selections

Line development

Hybridization & Composite development

Biotechnological interventions and markers





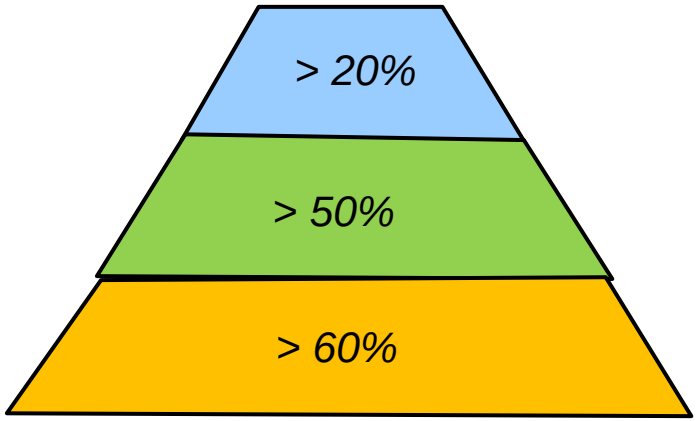
Jatropha yield IMPROVEMENTS (IRRIGATED & RAINFED) T/ha/year

Modern biotechnology is essential for making Jatropha based biodiesel viable

More and more countries worldwide with biofuel support policies

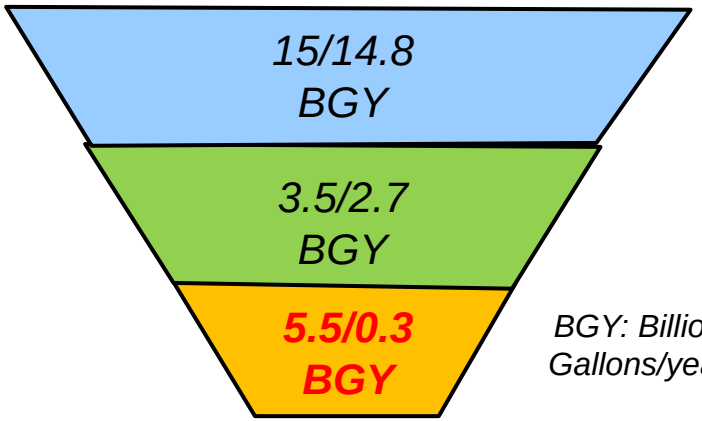
Government support encouraging development of advanced technologies for bio-ethanol and bio-diesel

US biofuel incentive system



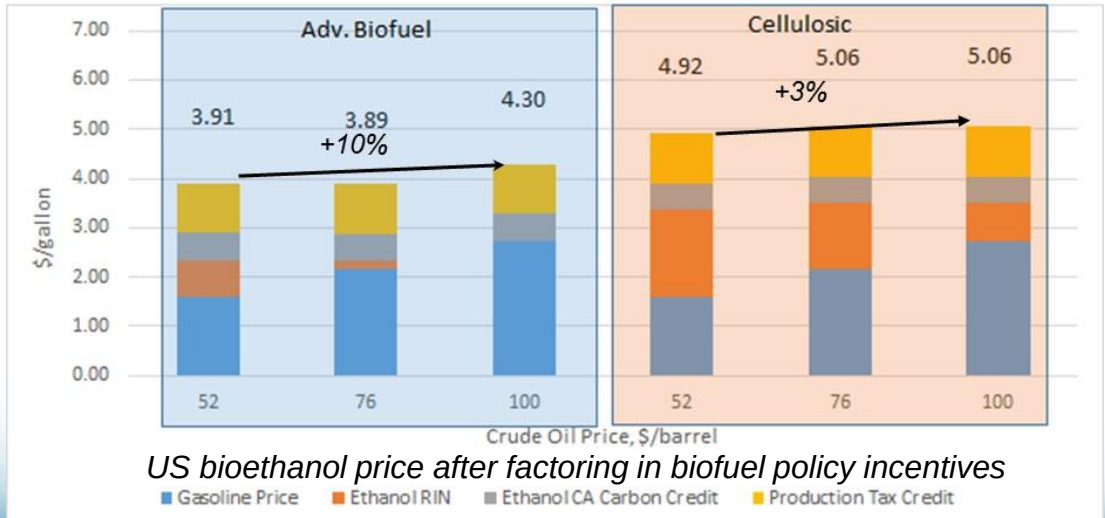
Biofuel Categories

- Renewable Fuel
- Advanced Biofuel
- Cellulosic Biofuel



BGY: Billion Gallons/year

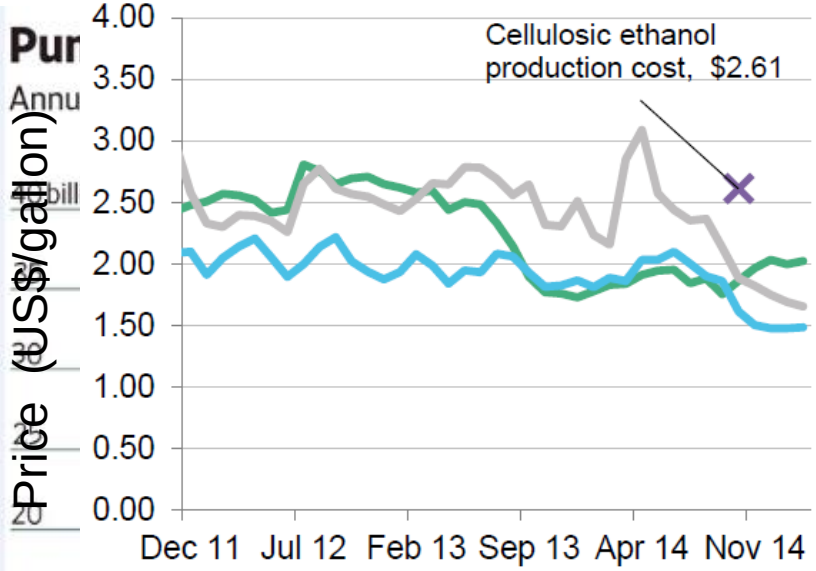
- Refiners/Importers are obligated to blend biofuels for each category at levels mandated by EPA.
- In lieu of blending biofuel they can fulfil obligation by purchasing RIN credits for relevant category.
- RIN Value for a category gets decided by demand/supply for that category of RIN

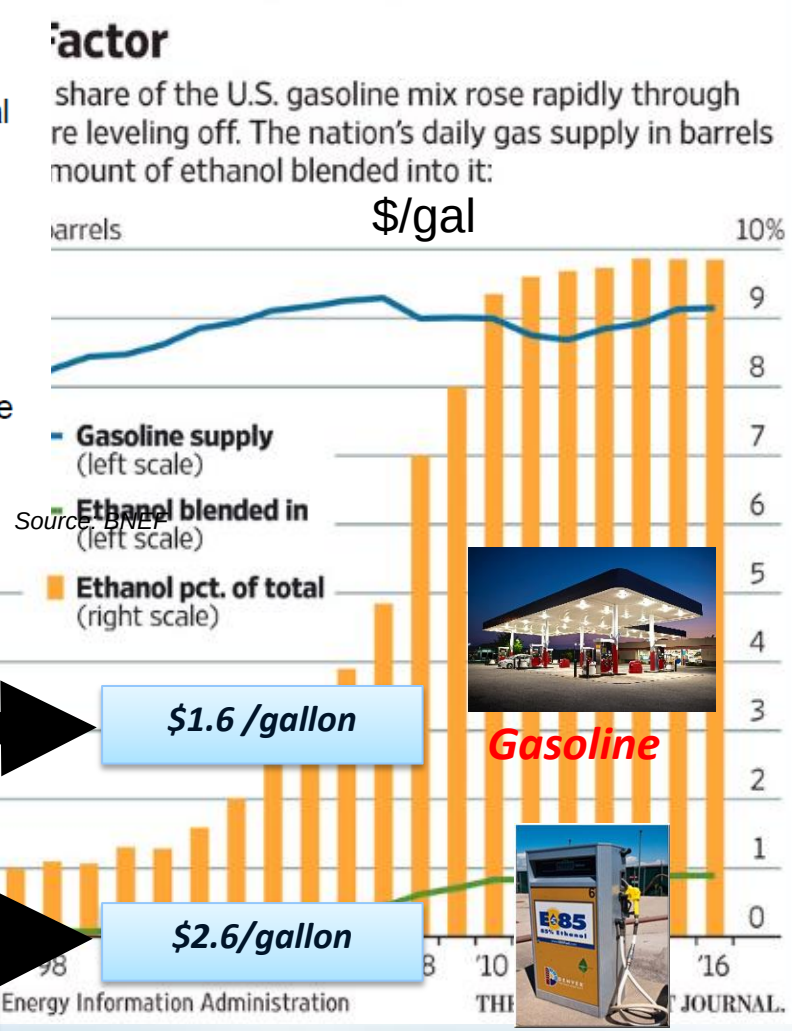


US bioethanol price after factoring in biofuel policy incentives

RIN mechanism ensures significant price incentives for emerging categories of biofuels

Bio-ethanol evolution: 1st generation corn ethanol and 2nd generation cellulosic ethanol





Source: BNEF

Feedstock Costs

Crude Oil

$8.5/mmBTU @ $50/bbl

Carbon Economy > 90%

$1.6 /gallon

Gasoline

Biomass

$3.6/mmBTU @ $50/T

Carbon Economy approx. 30-35%

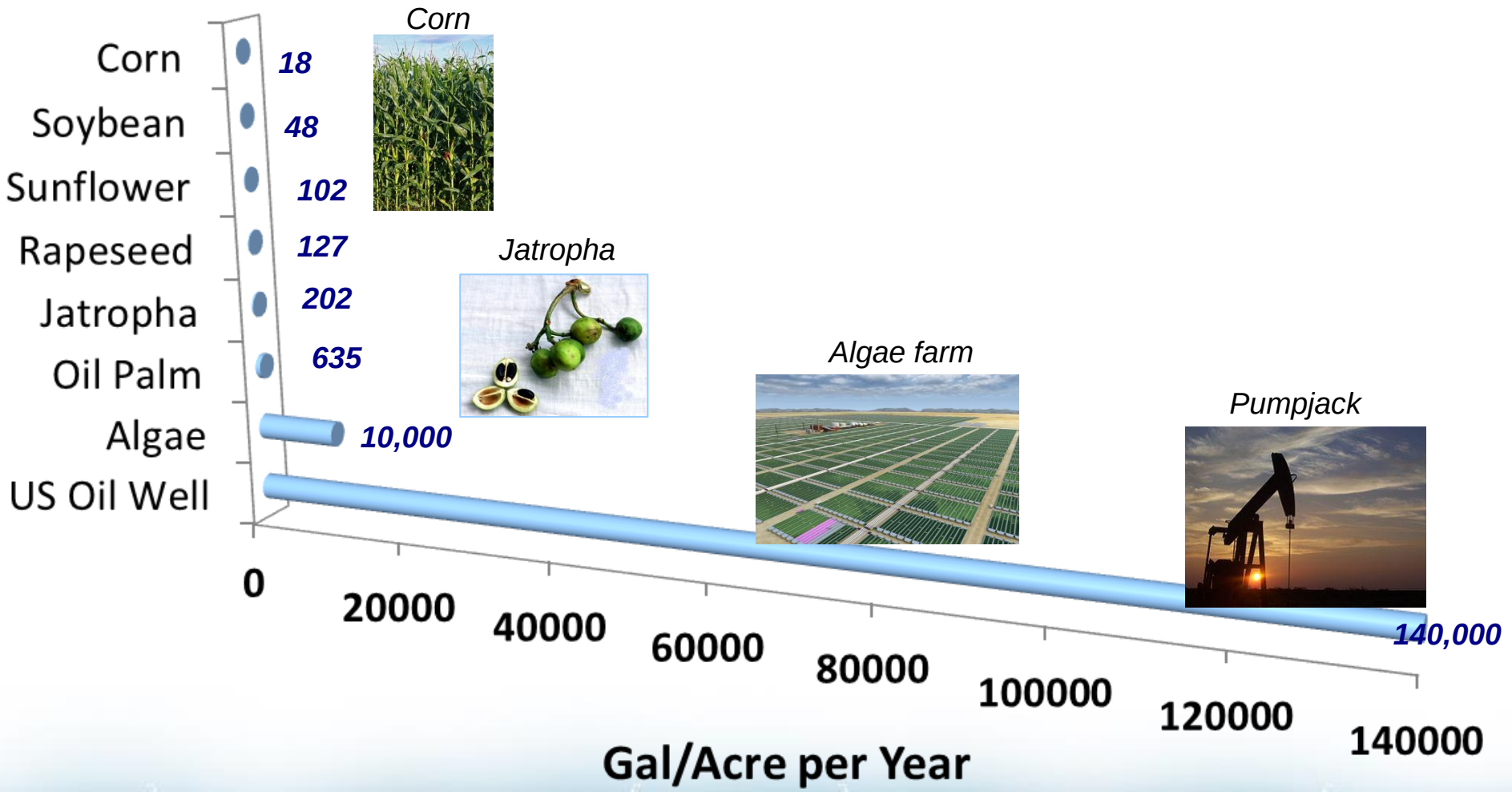
$2.6/gallon

Cellulosic Ethanol

Mandate driven global market for 1st generation ethanol beginning to get saturated

2nd generation cellulosic ethanol challenged by high feedstock and capital cost

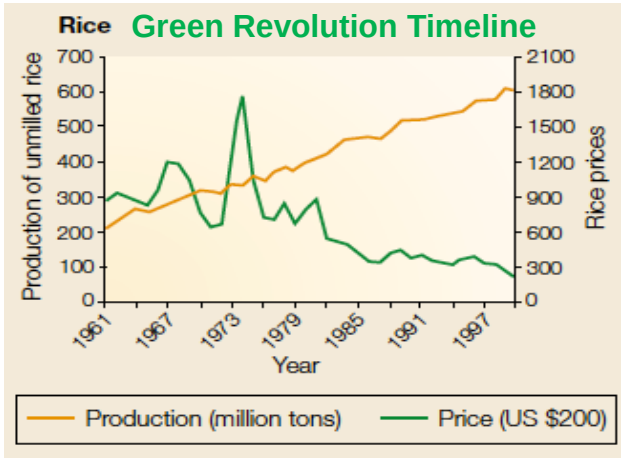
Algae are efficient converters of sunlight to energy



To compete with fossil crude oil, even algae will need higher crude prices and/or C-tax

Advanced biotechnology has transformed agriculture

biotech cotton has made significant contribution to the incomes of **>16.5 million** farmers and their families in **CHINA, INDIA, PAKISTAN, MYANMAR, BURKINA FASO, & SOUTH AFRICA**



Advances in biotechnology

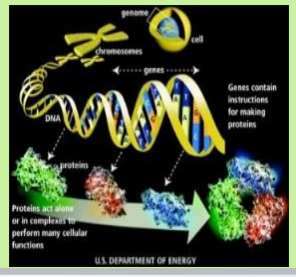
- **Increased food production per acre**
- **Reduced production cost for major food crops**

Agricultural biotechnology tools are applicable for advancing algal technology

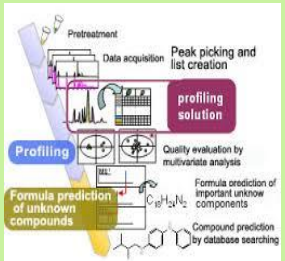
Gene Discovery → ***Transformation*** → ***Trait Integration*** → ***Field Validation***

Transformation

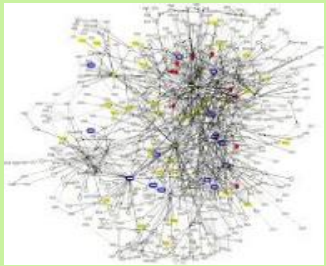
Genomics



Metabolomics



Systems Biology



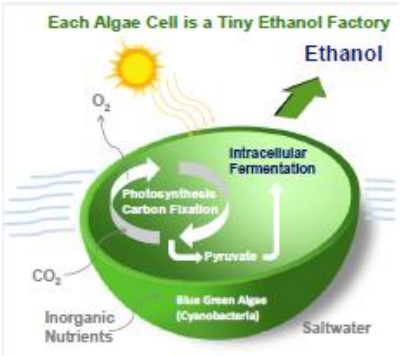
Field Testing

Advanced bio-technology tools can improve algae yield, robustness, stress tolerance and other desirable traits

Algae for producing ethanol: RIL partner Algenol

Three core components of Algenol's Direct to Ethanol® process

World's Most Productive Algae Platform



85% of CO_2 to products

Specialized VIPER™ Photobio-reactors

4 week production cycles followed by algae separation from EtOH-H_2O mixture

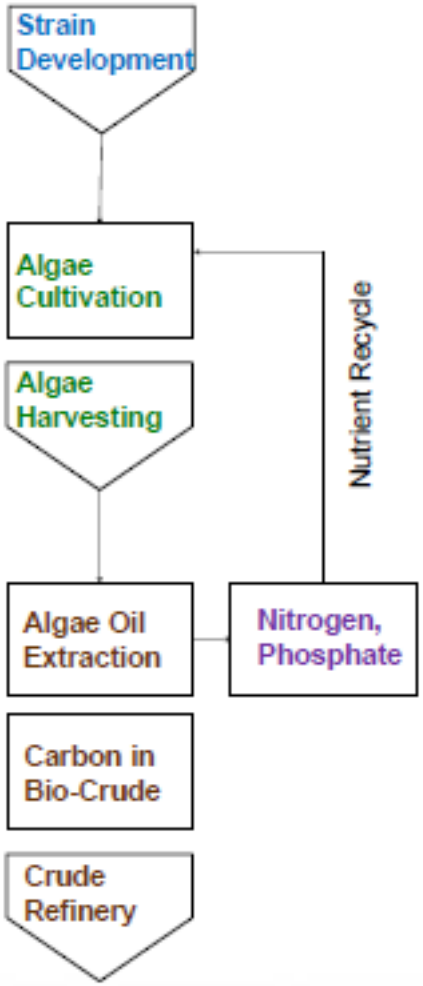
Energy efficient downstream processing

Proprietary EtOH dehydration and green crude from spent algae

Algae act as link between green fuels, fresh water and carbon reduction

Different algae to hydrocarbons options being evaluated at RIL R&D

Cultivation / growth in ponds or photo-bioreactors



Improved understanding of fundamentals of photosynthesis is allowing unique breakthrough technology development

Testing of alternate overall integrated production platforms in RIL R&D facilities will allow meeting commercial targets for capex & opex

Hydrothermal liquefaction (HTL) scale-up

WET ALGAE

HTL
350°C/206 bar
30-60 min

GAS

SOLIDS

Separations

ALGAL BIO-CRUDE

Aqueous phase to RECYCLE

HTL expedites natural process of oil & gas formation (< 60 minutes against millions of years)

HTL @ Gagva (2015)

Scale-up by factor of 6,500

First experiment in RIL (2012)

- Handles wet algae (80% water); No need to dry
- Yields ~ 50% bio-crude yield, independent of oil content of algae
- Largest demo facility built in the world
  - Sufficient scale for reliable commercial facility design
- Scale-up challenges addressed
  - ✓ Efficient reactor design
  - ✓ Hydraulics & heat exchanger design to suit Non-Newtonian materials
  - ✓ MOC to meet severe reaction conditions
  - ✓ RIL patented catalyst gives maximum biocrude yield
- HTL, a platform technology for effluent/sludge treatment

Successful in-house design and scale-up of a complex reactor and process

Today's waste – Tomorrow's wealth

Industrial effluent

Raw Sludge

Food waste

Conventional

Anaerobic digestion

Remainder Sludge

To fertilizer processing

COST!!

Bio-gas

Effluent water

To waste water treatment

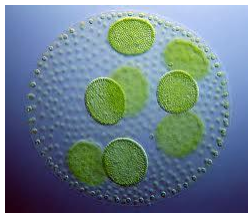
HTL/CHG

Energy

Clean water

Hydrothermal processing is a clean and fast pathway for wastewater treatment

Summary

	1st generation Corn Ethanol	1st Generation Biodiesel	2nd Generation Cellulosic Ethanol	3rd Generation Algae to Ethanol & Hydrocarbons
				
Global commercial production, 2014 (gal)	*24.6 billion*	*19.9 billion*	*< 0.1 billion*	*Zero*
India production (gal)	*~ 0.2 billion*	*~ 0.02 billion*	*Zero*	*Zero*
Global outlook	*Growth will plateau as mandates are met*	*Mostly from palm oil, soybean oil, rapeseed oil; Poised to grow*	*Significant capacity coming online but feedstock cost and capex are challenges*	*Focus includes high value chemicals that are less sensitive to falling crude prices*

Key challenges –

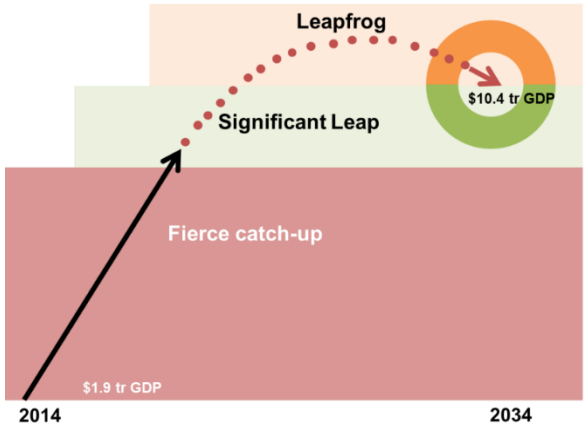
- ***Availability of feedstock***
- ***Cost of feedstock***
- ***Customer's appetite for premium for green products***

Need breakthrough innovations to make biofuels viable

Mind set change: From relay to synchronous dance

Organizing scientific research on the scale of big operatic and theatrical production is still something new in science and engineering

Innovation = Creativity X Execution



Government policy, support & drive for "Invent in India"

Raw material Flexibility

Collective Mandate:
Science for Solution, Technology for Transformation, & Innovation for Impact

Inclusive Innovations to meet needs of Aspiring Resource Poor Indians

OPEX Efficiency

CAPEX Efficiency

I Would Prize Every Invention of Science Made for the Benefit of All – Mahatma Gandhi

Summing up

Innovation Led Growth

Growth is Life

THANK *YOU*