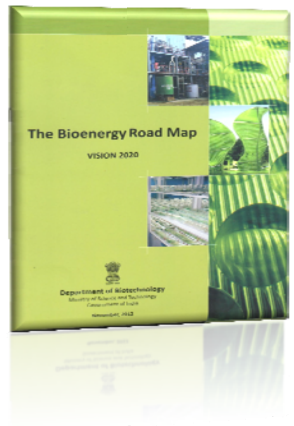

THE BIOENERGY ROAD MAP

VISION 2020
Department of Biotechnology (DBT)
Ministry of Science and Technology
Government of India

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(This roadmap has been prepared through a consultative process by an expert group of scientists involving all researchers from institutes, universities and industries working in this area across the country.)

THE BIOENERGY ROAD MAP

VISION 2020

Environmental and energy security concerns are forcing countries world over to shift to alternatives like biofuels in the form of bioethanol, biodiesel etc. Since biofuels can be produced from a diverse set of crops each country is adopting a strategy that exploits the comparative advantages it holds with respect to such crops. It is important for us to develop a clear strategy and road map for the bioenergy sector utilising optimally the biomass resources available to benefit the bioeconomy.

1. VISION 2020: Create a biotechnology enterprise equipped with viable green and clean technologies for achieving bioenergy security.

The Vision document outlines what our long-term goals should be if we are to truly achieve cost-effective clean energy development with recent refinements to the technology. The Vision document now provides a complete framework for achieving the set goals or targets.

2. Goals and Targets

- 20 per cent blending of fossil fuel by 2020
- Commercially viable lignocellulosic ethanol produced from agricultural and forestry waste
- An economically cost efficient system available for algal production and also a commercial scale technology for production of biofuels from algae either through harvesting and oil transesterification or direct conversion to biooil
- Next generation biofuels from different biomass feedstock.

3. Where are we today?

- No commercially available second generation biofuel technologies are currently available. This national need demands a paradigm shift from reactive to proactive technologies.

4. Strategy to achieve the vision

i. Promote technology innovation by creating an enabling environment through Centres of Excellence and Network Programmes.
ii. Support and strengthen appropriate infrastructure creation and capacity building.
iii. Make a strong, long-term commitment to implement cost-effective clean energy as a resource.
iv. Provide adequate, timely and stable programme funding to deliver cost effective clean energy technologies.
v. Implement appropriate policies and regulatory mechanisms and
vi. Institutionalise enabling mechanisms to promote inter-sectoral collaboration with industry and academia.

5. Implementation plan for next five years

i. Launch a Strategic Research Programme to achieve the Goal of 20% blending by 2020.
ii. Set up at least five joint centres on the similar model as existing Bio Energy Centres.

iii. Create a Team India of at least 100 scientists in interdisciplinary research areas.

iv. Support basic research R&D programmes in different cutting edge science areas, which are critical to provide a detailed understanding of the process involved and modifications which are feasible. This would be networked to the Energy Centres.

v. Train at least 100 Post Doctorate Overseas in specialised areas such as synthetic biology, enzyme and protein engineering, metabolic engineering, systems biology, etc.

vi. Attract at least 25 overseas scientists to the Centres through Energy Bioscience Fellowship and institute at least five chairs, one in each Centre.

6. Science Programme Strategy

I. Strategic Research Programme

Commercial production of biofuel from different feedstocks for 20 per cent blending

Focus to be on Technology development and optimisation for conversion:

- Biodiesel
- Bioethanol
- Green Diesel
- Algal Biofuel
- Biobutanol
- Biohydrogen
- Biochemicals
- Fuel Cells

Biodiesel

Gaps

The Indian biodiesel specifications are very stringent, therefore it requires some moderation of products to meet specifications. Indian R&D units have developed the process know-how but the engineering design and equipment selection is not offered. There is no Indian R&D based unit which can offer complete technology package on lump-sum turnkey basis and that is probably the main reason why all commercial plants set up till now in India are based on imported technology. Large quantities of water are essentially needed for washing to remove catalyst traces. All major auto companies have expressed reservations on blending of more than 10 per cent bio-diesel in diesel because of the problems of gum formation and for stability issues.

Interventions required

There is an urgent need to address some drawbacks of homogenous catalyzed production process related to

- Feedstock quality which needs to be completely refined for processing; reactants/catalyst to be moisture free
- Operation problem related to disposal of large amount aqueous effluentgenerated.
- Quality of glycerol produced during the process being very poor. Need for development of glycerol refining technology in the country.
- Development of catalyst system that can operate at methanol reflux temperature.
- Solid catalyst having high catalytic activity and recyclability
- Lower capex and opex
- Complete process and engineering know-how for scale-up
- Commercial availability of catalysts
- Enzymatic catalysis with reusability of enzymes

Green Diesel

Gaps

- Optimising of the processing conditions, hydrogen consumption and catalyst for conversion of varied feed stock to green diesel.
- Use of expensive metallurgy required to handle acidic feed stock and products.
- Production of process intermediates like carbon monoxide, carbon dioxide and large amount of water impacts activity of hydro processing catalyst
- Development of robust economically viable technology capable to handle any type/quality of feed stock
- Large scale commercial trials

Interventions required

- In order to achieve a large scale commercialisation of this technology, survey of available veg oil, costing of selected technology and metallurgy required in hydro processing unit need close attention.
- Development of catalyst which is cheap, having longer life and good selectivity.
- Need to develop good & cost effective oil demetallation and de-gumming processes
- Study the overall heat balance in refinery

- Life cycle analyses needs to be performed for green diesel produced via hydro processing route in Indian context. Therefore, the energy return and overall environmental impact can be quantified.

Bioethanol
Gaps

- Novel enzymes with high specific activity, mutation and modification of hydrolytic enzymes to improve their catalytic efficiency, and development of processes to produce these enzymes at minimal cost should be the major priority for the scientific research in the area of lignocellulosic alcohol.
- The technology must be within reasonable bounds of capex (Capital Expenditure) and opex (Operational Expenditure).
- The technology must be robust and sustainable, and this implies many aspects like being zero waste, economically viable, people friendly, and suitable for a variety of feedstocks.

At present no technology anywhere in the world fulfils the above requirements. And therefore following interventions are required.

Interventions Required

- Physico-chemical characterisation of different biomass varieties and linking these to their pre-treatment ‘friendliness’.
- Set up a multi-technology multi-feedstock pilot plant as a national facility.
- Mount new initiatives as well as coordination of on-going and new efforts engaged in enzyme design/screening, expression and production for hydrolysis of celluloses (separate or combined with fermentation). The efforts made across the country need to be catalogued and evaluated. It is possible that there would be some strains and enzymes with novel and desired features.
- A number of innovations need to come through on fermentation technologies for biomass derived sugars. New strains for both hexose and pentose fermentations as well as new process designs for increased bioreactor productivities are a must for making the overall technology acceptable.
- Strains for SSF need to be developed to provide high overall productivities.
- Development of low CAPEX and OPEX technologies for purification and dehydration of ethanol also requires engineering.

- Sustainable technologies for conversion of lignin to liquid fuel need to be developed.

Algal Biofuel
Gaps

- Improved strains for better yields
- Optimising of the biomass production conditions
- Optimisation of downstream processing
- Large scale commercial trials

Interventions required

- To explore cost effective feedstock and novel efficient strains for biofuel production.
- Development or selection of a strain that provides a optimal FFA composition and yields
- Optimise photobioreactor systems and raceway pond cultivation
- To develop proper technology to overcome the oil extraction problem.
- To develop efficient *in situ* recovery process technology.
- Attempts for improvement of productivity must be made using different strategies like extraction and continuous esterification

Biobutanol
Gaps

The major problems related to butanol production are

- Simultaneous production of three products and their subsequent separation
- Low yield of butanol on sugar substrates
- Low tolerance of strains for butanol and their sporulation tendencies
- Low overall volumetric productivity in g/L/h.
- Cost effective biobutanol production at commercial scale is yet to be developed by using non-food feedstock as a substrate. Though biobutanol production is already established at pilot scale and is fast approaching the commercial scale overseas, it is yet to be developed in India.

Interventions required

- Explore cost effective feedstock and novel efficient microbes for biobutanol production.

- **Optimal strain development**: Development or selection of a strain that provides a combined ABE or AB yield of at least 0.4 to 0.45 g/g of fermentable sugar. This could be *Clostridium spp* or any other strain. This would require exploration of all possible methods for arriving at suitable strains from simple random mutation to directed mutation.
- Develop proper technology to overcome the solvent toxicity problem.
- Develop efficient *in situ* recovery process technology.
- To develop new fermentation and recovery processes based on the metabolically engineered strain/s.
- Attempts for improvement of productivity must be made using different strategies like extractive fermentation and continuous (chemostatic) fermentation with cell recycle and high cell densities.
- Metabolic engineering of aerobic systems containing the biobutanol production genes.
- Butanol recovery strategies to a large extent depend upon relative and individual concentrations of the fermentation products. Combination of membrane and distillation methods will need to be worked out for cost effective recoveries.

Biohydrogen

Biohydrogen production technology is not yet fully established at pilot scale and requires an extensive investigation to make this process commercially viable at national and international level.

Gaps

- Oxygen sensitivity of hydrogenase enzyme.
- Partial pressure inhibits hydrogen production.
- Designing of efficient photobioreactor is yet to be developed. Investigations are required to design and construct photobioreactor with a view to capture light effectively for enhanced biohydrogen production
- Research studies concerning structural and functional characterisation of mesophilichydrogenase enzymes (by site directed mutagenesis approach) to enhance oxygen tolerance limit, are lacking and needs further attention.
- Characterisation of thermophilichydrogenase enzymes also require extensive investigation to gain insight about the genetic crux lying behind the oxygen tolerance of these enzymes.

Interventions Required

- Exhaustive screening of efficient hydrogen producing dark and photo fermentative microbes including photosynthetic algae from diverse geoclimatic regions, by using waste materials and non-food feedstock.
- Molecular engineering of oxygen tolerant efficient hydrogenases by employing site directed mutagenesis approach, for optimum dark and photo fermentative hydrogen production.
- Identification of novel O_2-tolerant hydrogenases from environmental microbes.
- Development of technology to overcome inhibitory effect of partial pressure during hydrogen fermentation.
- Development of recombinant strains for enhanced biohydrogen production at pilot scale.
- Modelling and simulation of the dark and photo fermentation process for optimum hydrogen production at a pilot scale.
- Metabolic engineering of strains to enhance hydrogen production/ to gain insight about regulatory and metabolic pathway of hydrogen production.

Biochemicals

Gaps

- Production of power and steam from lignin and effluent streams from biofuels and biochemicals production processes is not yet established.
- Cost-effective technologies for the conversion of biomass, sugars and glycerol into biochemicals has not been well studied or well understood in India.
- Micro-organisms capable of producing biochemicals have not been well studied in India. The synthetic and metabolic pathways to producing such biochemicals have not been well understood in India.
- Chemical catalysts (heterogeneous and homogeneous) and the associated reaction mechanisms in the conversion of sugars to chemicals have not been well studied in India.
- The impact of certain constituents in the feedstock sugars and their impact on the chemical and biochemical reactions have not been well studied in India.

- There is a lack of understanding in the fermentation processes required for production of biochemicals and the downstream processes required for recovery, conversion, and purification of biochemicals.
- Current issues with the fermentation route include yield from sugars, fermentation time, and the titers achieved.
- Current issues with the chemical catalysis route include selectivity, yield, effect of inhibitors, and tar formation.
- The downstream processing requirement for the production of biochemicals is not well understood.
- Design and engineering of industrial plants to produce biochemicals has not been studied.
- Lifecycle Analysis of the processes to produce biochemicals is not well understood.
- Integrated BioRefinery technology has not yet been demonstrated at any substantial scale.

Interventions required

- Target bio-chemicals must be identified. Such compounds must either be the final biochemical or must be a precursor compound required to make the final biochemical. In the case of precursor compounds, as far as possible, they must utilise as much existing infrastructure as possible in their conversion to the final biochemical.
- Target process performance parameters for the production of each specific biochemical must be set. These must include the capex and opex parameters, the rates, titers, selectivity and yields for the processes.
- Candidate micro-organisms with the potential to produce the target biochemicals must be identified. Screening of candidate micro-organisms in our culture banks must be conducted to down select micro-organisms for R&D. Classical and directed mutagenesis must be pursued to improve the capability of the down-selected micro-organisms to produce the target biochemicals must be pursued.
- Synthetic and metabolic pathways to produce the target biochemicals must be studied. Genes encoding on specific enzymes required in the pathways must be understood and candidate strains possessing such genes must be identified. Host organisms suitable for the production of biochemicals must be identified. The tools and

techniques for inserting such genes and pathways into host organisms must be developed.

- Downstream processing technologies for the recovery and purification of target biochemicals must be identified and developed.
- Technologies for the conversion of the target biochemicals into the final biochemicals must be developed.
- Lifecycle analysis on the technologies for the production of target biochemicals must be conducted.
- The technology development must include the consideration of the design and engineering of commercial plants early in the development of the technology.

Fuel cells

Gaps

- There have been limited examples of projects linking bio-based fuels with FC. Although some niche opportunities may exist in the near term, the commercial viability of FC with bio-based fuels is yet to be demonstrated.
- It will require a realistic and unified vision moving forward. The barriers to development of such projects need to be tackled.
- At a macro level, obstacles that impede the development of distributed generation in general will ultimately impact the development of technologies. Similarly, competition between FC and potential alternatives, like efficient internal or external combustion engines, micro-turbines, solar, and wind, will necessarily affect the potential for using bio-based fuels with FC.
- Competition between bio-based fuels and low cost fossil fuels is another concern. Roadmap for using bio-fuels with FC, in the short and long-term, needs to be evolved giving due consideration to these larger issues.

Interventions required

- Further developments are required to see regular commercially viable application of FC systems.
    - The techno-economic issues in fuel pre-treatment and FC integration need to be addressed.
    - The reforming and gas-cleaning technologies are yet to completely mature.

- While FC technologies are approaching commercialisation, there is a degree of uncertainty about the prospects of utilising fuel cells with bio-based feedstock.
- Fuel clean-up systems also need to be further developed. The present systems have been able to significantly reduce the amount of contaminants reaching the FC, however the costs associated with fuel clean-up are still high. FC requires systems that have greater flexibility, because many bio-based fuels vary in composition over time and over agro-climatic zones.
- Raw feedstock cost is another critical factor. It impacts the potential project viability. The use of biomass waste streams that would otherwise require disposal, i.e., have zero or negative costs, can have a positive impact on project economics. However, it is seen that the market price of the feedstock, whether cultivated or waste, disproportionately increase over time.
- Genetic engineering could be applied toward improving the characteristics of dedicated biomass energy crops and may positively influence feedstock economics.

Basic Research Science Project

i. Feedstock improvement

ii. Algal Biofuels
   Microalgae
   Macroalgae

iii. Synthetic biology

Feed Stock improvement

***Jatrophacurcus* for biodiesel**

Gaps

- Productivity should be high, stable year after year to meet feedstock requirement. A targeted seed production should be 7.5 MT/yr/ha.
- Crop should withstand the harshness of degraded and underutilised sites as available in the country for cultivation of *Jatrophacurcas*
- Plants should be disease resistant and robust
- Plants should have least irrigation requirement and drought resistant
- Plantation should not add carbon footprints and should be environmentally sustainable
- Plantation should be economically feasible for farmers, SHGs, NGOs and also for industry.

- *Jatrophacurcas* chain should bring additional benefits from use of unused cake, fruit husk, vegetative biomass etc.
- Non-toxic varieties of *Jatrophacurcas* should be developed so as to produce *Jatrophacurcas* that has cake good as feed. Several tons of this cake will be available after processing of oil from the seeds.
- The biomass is also a good stock for generation of electricity, biofertilisers, biopesticides and vermin composting. Utilisation of waste will add to the economic feasibility of *Jatrophacurcas*.

Interventions required

- Cloning of fatty acid biosynthesis genes and development of molecular markers
- Elites and location specific accessions and “cultivars” to be identified for specific wastelands
- Productivity along with cultural practices (nursery & field) to be made available for large scale cultivation
- Improved “varieties” needs to be developed and sufficient material to be made available for bulking in the country

Algae biofuels

Microalgae

Gaps

There is a need to engage biochemical engineering groups in bioreactor design best suited for the purpose and our country. There is a need to fund large scale algal raceway ponds that could provide opportunities for capable groups to develop downstream algal biofuel technologies and develop appropriate technologies incorporating the concept of a bio refinery.

Interventions required

- Algal strain selection/development
- Algal growth at required scale and economy
- Algal harvesting and processing to produce dense energy source/s
- Refining the densified energy source to liquid fuels of desired properties

Algal proteins offer interesting possibilities. If all transport fuels were to be replaced by micro-algae biodiesel considerable quantities of proteins would become available as well.

That is 40 times more than the amount of protein in the soya that Europe imports each year. Thus, algae would allow the production of food and feed proteins as well as sufficient quantities of biodiesel.

Macroalgae

The most important aspect is to bridge the gap in knowledge on large scale cultivation of seaweeds and its use as a raw material for fermentable sugar production.

First, seaweeds that can grow fast to produce fermentable sugars without affecting the local sea environment has to be identified and large scale cultivation and harvesting systems in the ocean needs to be developed.

Suitable hydrolysis methods need to be developed to obtain fermentable sugars which can be further converted to fuel and value added products. Since the seaweeds will be grown under saline conditions, it is expensive to wash them before processing further. Hence, the hydrolysis and fermentation process will need to be marine based. For this the focus must be on:

- Seaweed strain selection/development
- Development of ocean culturing systems
- Processes for the production of fermentable sugars
- Development of marine based hydrolysis and fermentation systems

Synthetic biology

- Producing new biofuels through synthetic biology
- Gene regulation to engineer micro-organisms to convert sugars from biomass to alkanes and other oil like hydrocarbons

Training and capacity building

Considering the points as discussed above, it is recommended to create institutional mechanism for medium to long term training and capacity building in the areas as mentioned above.

- There is a need to establish institutional network and protocol to engage the research and educational institutions, scientific agencies, recognised laboratories and public agencies, to share their scientific information and experience in the relevant field as discussed above.
- There is a need to attract high skilled post doctorate professionals by offering attractive remuneration to encourage them to pursue their research activity in India instead of in overseas countries.

- Workshops, seminars should be conducted in the relevant area to share the international experience among scientific community and to assess good regulatory models among regulatory authorities.
- There is a need to host as well as to participate in technology innovation centres
- It is recommended to initiate and fund mission mode target oriented projects
- It is required to encourage the existing one as well as to create new research centre for focusing research in relevant field
- Private sectors are required to develop and commercialise the product and process resulting from the programme, to support and participate in the collaborative R&D projects, as well as to support for creation of technology innovation centre in order to attract the high skilled talented scientists.

International Cooperation
There is a need to enhance our own capacity to comply with our commitments and to enable our flow of resources. Hence it is important that India makes a concentrated effort to

- participate in major international events to develop network and enhance environmental cooperation
- participate in regional and bilateral programmes.
- initiate a programme for exchange of scientific professionals having expertise in the relevant area.

The Way Forward
The scientific community work towards creating "Bioenergy Team – India" for achieving the goals and targets we have set for ourselves. This will contribute significantly the country's bio economy roadmap.

Bioenergy Centres
Feedstock Development
Biofuel Technologies
Vision 2020

Indo –US JCERDC
Capacity Building/ Fellowships
Monitoring