IEA Bioenergy

Newsletter

for IEA Task 26

Biotechnology for the Conversion of Lignocellulosics to Ethanol

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TASK MEMORANDA

J. N. Saddler
mailto:saddler@interchange.ubc.ca

From the Task Leader

As indicated in the main body of this newsletter, thanks to the good work of the various presenters at our IEA workshop "Commercialization of Biomass to Ethanol" we had a very successful meeting in Gatlinburg, Tennessee that was attended by over 70 people. We were also fortunate to be allowed to hold our workshop within the 22nd Symposium on Biotechnology for Fuels and Chemicals which was again ably organized by Brian Davison and his colleagues from the Oak Ridge National Laboratory. It was apparent from both the presentations within our IEA Bioenergy Task 26 workshop and the general symposium that several areas of research have progressed significantly, such as the fermentation of mixed pentose/hexose sugars to ethanol, while several groups such as BCI and Iogen will be demonstrating the technical feasibility of the overall biomass-to-ethanol process in the near future.

This is the last reminder of our IEA Bioenergy Task 26 session for the PACIFICHEM meeting that will be held in Honolulu, Hawaii in December. Although it is now too late to send abstracts to ACS, a few e-mailed abstracts to David Gregg (djgregg @interchange.ubc.ca) might still be incorporated into our session. Details on the Hawaii meeting are attached at the end of this newsletter.

As our editor, David Gregg, indicates below, we will only have 1-2 more newsletters under the current triennium program of work that runs from 1 Jan 1998 to 31 Dec 2000. Negotiations are underway at the IEA Bioenergy Executive Committee meeting, held 29-31 May in Utrecht, Netherlands, about the structure of the Tasks for the next 3 year program of work that will commence in January, 2001. More details on our proposed future structure will be appearing in the next newsletter.

Thanks again to all the presenters and participants that made the Gatlinburg workshop such a productive meeting. ♣

EDITORS NOTES

D. J. Gregg
mailto:djgregg@interchange.ubc.ca

This is the last year of the current triennium for Task 26 and we are currently in the process of determining the level of participant interest and structure of continuance.If you have found issues of this newsletter to be of value, please inform the Executive Committee member(s) and/or IEA Task 26 country representative from your country of the importance of continuing this type of forum.

If it is supported by enough countries, the new Liquid Biofuels Task which should run from 2001-2003, will build on the combined strengths and successes of the existing Task 26 and 27. The overall objective of this future Task is to provide participants with comprehensive information to assist them with the development and deployment of biofuels for motor fuel use.

The Task will address both policy and technical issues relating to liquid biofuels, particularly ethanol and biodiesel. We will provide information and analyses on policy, regulatory, and infrastructure issues to assist participants in their efforts to establish biofuels markets. We will also address technical issues related to development of advanced conversion technologies. In addition, we

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will deal with the specialized issues relating to biodiesel. This arrangement allows each of these components to benefit from the coordinated interaction with the others.

The Task will conduct work in three areas. Work that began in Task 27 on policy, regulatory, and infrastructure issues will be continued and expanded with increased stakeholder involvement. Work will also build on the successes from Task 26 to catalyze cooperative RD&D projects that will help participants develop improved processes for converting lignocellulosic biomass to ethanol. A third project will also address specialized issues relating to biodiesel. The Task will provide for cohesive information dissemination and outreach through the establishment of a broad-based web site and periodic newsletters. Stakeholder involvement will actively be encouraged in all three project areas. The Task will also continue and expand its interactions with other IEA Bioenergy Tasks, other IEA Agreements, and other related groups.

Deliverables for this Task include topical reports, analyses, workshops and proceedings, newsletters, periodic progress reports, annual accounts, and other information products. These are described in more detail in the full proposal. If supported, the Task will begin in 2001 and operate for a three-year period. The combined work is expected to be productive from the start since it combines the successful ongoing efforts of Task 26 and 27.

There will be a strong tendency to continue to profile the technical advances but this will be tempered with discussions on various governmental policies (environmental and institutional) and collaborative strategies (government, industry and research groups) that are currently operating effectively. An example of this type of strategy currently under way in the Netherlands is discussed later in this newsletter.

Again do not forget that there is still one more meeting for this current Task in Hawaii this coming December. We were hoping to have a grand finish to the current Task by having a good turnout. This will not be the case with the current level of abstracts that we have received so far! If you do want to present at this meeting you will have to immediately e-mail me a copy of your abstract as the deadline is officially past (djgregg@interchg.ubc.ca) . ♣

RECENT ACTIVITIES

Twenty First Symposium on Biotechnology for Fuels and Chemicals, Gatlinburg, Tennessee, U.S.A., May 7-11, 2000.

This was a very successful symposium, with over 180 participants, a total of 35 oral presentations and 170 posters categorized into the areas of:

- Feedstocks: Production, Modification, and Characterization
- Applied Biological Research;
- Processing Research;
- Emerging Opportunities for Industrial Chemicals;
- Bioenergy and Bioproducts;
- Industrial Chemicals
- Enzymatic Processes and Enzyme Production.

For more information on this conference or to purchase a copy of the conference proceedings please contact:

Dr. Brian Davison
Conference Chairman
Oak Ridge National Laboratory
P.O. Box 2008, Bldg. 4505
Oak Ridge, TN
USA 37831-6226
Tel: 423 576 8522
Fax: 423 574 6442
mailto:bod@ornl.gov

Our IEA network sponsored a Special Topic Discussion Group focused on the "Commercialization of Biomass to Ethanol", which, was held within the larger Gatlinburg Symposium on May 10, 2000. The workshop had 70 participants from 11 countries and represented academia (30 participants), the public sector (19 participants), consultants (5 participants) and the industrial sector (15 participants).

The goal of this workshop was to show participants that we are close to demonstrating the technical viability of an integrated biomass-to-ethanol process and that progressive technical advances and policy decisions will likely greatly enhance the economic attractiveness of the process.

There were nine individuals that presented material (10-15 minutes each) with questions being brought up after each presentation. The highlights of the presentations and the names and addresses of the presenters (the presenting author in a multiple author presentation is marked with an asterisk i.e., *) are indicated below.

BRAZIL

Gisella Maria Zanin, Cesar C. Santana, Elba P.S. Bon, Raquel C. L. Giordano, Flávio F. De Moraes, Silvio R. Andrietta, Carlos Coelho De Carvalho Neto, Isaias C. Macedo, Djalma Lahr Fo, Luiz P. Ramos, and José D. Fontana*
Universidade Estadual de Maringa
mailto:gisellazanin@cybertelecom.com.br

Although Luiz Ramos from Federal University of Paraná was originally slated to present, it was obvious with the imminent arrival of his second child, regretfully had to make a more important appearance elsewhere! Gisella filled in admirably and provided us with the following information.

Brazilian Bioethanol Program

Brazil is the largest producer of bioethanol (from sugarcane) and has been producing fuel ethanol since

1975. Three factors led to the implementation of a national program to introduce fuel ethanol: trade deficits as a consequence of:

- high imported crude oil prices (from $600 million in 1973 to $2.6 billion in 1974);
- Brazil in 1973 imported 34% of its total energy consumption in the form of crude oil. This dropped to 18% after implementing the ethanol program.
- The most important factor was the major drop in sugar prices from $1400/tonne in November 1974 to $268/tonne in December 1975. Sugar mill owners have always been a strong lobby in Brazil and the program represented an ideal solution to their problems. The production of alcohol allowed for flexibility in the sector, preventing large stockpiling of sugar by diverting any excess to ethanol production.

The Brazilian National Alcohol Plan was implemented in two phases. The first phase, started in 1975, and took advantage of the structure and capacity of existing sugar mills to produce only hydrated alcohol to replace tetraethyl lead as a gasoline additive. The proportion of ethanol was increased from 1.1% in 1975 to 16.7% in 1979, without having to modify automobile engines.

The second phase, beginning after 1979, involved the production of hydrated alcohol for direct use as an automobile fuel and required a complete modification of automobile engines. A number of factors contributed to the rise of alcohol-driven cars to a level of up to 96% of the industry's production by 1986. These included an agreement between the federal government and ANFAVEA, the official government representative of the Brazilian automobile industry, a favorable stable price for ethanol (hydrated held at 65% of gasoline) and lower industrialized products tax (IPI) for alcohol-driven automobiles. Very favorable financial incentives were also given to the sugarcane producers which resulted in a stunning 35% growth in the sector.

Problems with the Program

By 1980, several problems resulting from a variety of factors began to plague the program. The period of the "Brazilian miracle" was over and was replaced by a retraction of the country's economy. This meant the government was forced to redefine national priorities. Stabilization of the price of crude oil at about $10/barrel no longer made the substitution of gasoline with alcohol advantageous, as had been the case in past years. The government decided to reduce the price of ethanol to be paid to the produces. This price was set on the average cost of the different producers, but production costs varied significantly between modern, productive mills and outdated mills with high production cost, located in areas that were not traditionally sugarcane-producing regions. This difference in cost further aggravated the situation with outdated mills.

In 1986 a new reduction in the program incentives was introduced. The special credit line for the cultivation of sugarcane was cut, worsening the situation for the mills. The resulting lack of sugarcane caused a drop in production of 4 billion L of alcohol in 1987, which represented the difference between the installed industrial capacity and production capacity of the agricultural sector. The idle capacity caused the production costs to increase even further.

Brazil faced a crisis in 1988 when the growth in the sugar market, caused production to be diverted from ethanol to sugar, and a continuous growth in demand for hydrated alcohol led to the country importing ethanol and methanol.

Several unfavorable factors related to the production of alcohol-fueled vehicles also began to surface. Fuel supplies became unstable as the price of hydrated alcohol gradually increased in relation to gasoline. The federal government established tax incentives for gasoline-driven automobiles while also reducing the tax incentive for alcohol-driven vehicles. This combination of factors led the industry to reduce production of alcohol vehicles from 96% of total domestic sales in 1985 to 0.01% in 1997.

Nevertheless, ethanol still represents 51% of the liquid fuel consumed in Brazil (hydrated alcohol plus blends with other fuels) with 63% being hydrated alcohol fuel. The sugarcane industry still generates nearly 1.3 million direct jobs, 54% of which are directly related to ethanol production. Therefore, the maintenance of the program is not only strategically important from a technoeconomic viewpoint but also because its complete demise would impart a tremendous social problem for those regions where sugarcane is the main source of revenue.

Future Perspectives for the Pro-Alcohol Program

More than two decades since its creation, it is easy to recognize that the Brazilian Pro-Alcohol Program demands a redirection to minimize the huge conflict now existing between the historical policy and the current unfavorable reality (e.g., the "green" fleet stagnation). This redirection could be based on several actions, such as returning to the original policies of tax incentives and price control, implementing new policies to ensure availability of fuel, and establishing strict regulations for commercialization and good standards for quality control.

Based on a gradual return to the original ruling established for the national plan, one could anticipate a new boom in the Brazilian ethanol market based on the (re)creation of a renewed "green" fleet of taxis and other small transportation vehicles. This has been strongly supported by the government, and steps to somehow subsidize the future of this activity are now being studied (e.g., "green" taxation on diesel and gasoline consumption).

Apart from these structural changes, there is also a need for the identification of new market opportunities. This is being pursued by the government through the following actions:

1. An increase in the anhydrous ethanol content in fuel blends with gasoline from 24 to 25 to 26%;

2. The utilization of 3% anhydrous ethanol in diesel blends for diesel engines;

3. An increase of the aforementioned level of 11-13% by applying a cosolvent that could stabilize the anhydrous ethanol/diesel mixture.

Alternative technologies such as co-generation are still under evaluation, and their potential has been identified as promising for further reductions in the cost of producing ethanol from renewable resources. All these perspectives refer to ethanol as the main product. These government directions are under the responsibility of the Interministerial Council for the Sugar/Alcohol Industry and the National Department of Energy Development – Ministry of Mines and Energy.

Companies that produce ethanol (200 mills) have jointly created Brazil Alcohol S.A. with the mission of increasing the price paid by the large distributors to the mills and secondly to improve the quoted value of Brazilian sugar in the international commodity markets.

Utilization of sucrose in alternative and improved fermentation processes would also appear to be another target for research and implementation. There is a large array of opportunities ranging from PHB from cane molasses and bagasse formulations for cattle feed to low-cost media for SCP production.

Sugarcane bagasse should also be increasingly viewed as an acceptable starting material for new alternative agroindustrial businesses. These might include the production of biodegradable composites; lignocellulosic matrices for solid-state fermentation; and new material derived from natural polymers such as lignin, cellulose and hemicellulose.

THE NETHERLANDS

Ethanol for Fuel, The Approach within the Netherlands

Part 1 - Perspective of the Dutch Government

Arjan de Zeeuw
mailto:a.de.zeeuw@novem.nl

Novem (Nederlandse onderneming voor energie en milieu) is the Netherlands agency for Energy and Environment. Novem is a service organisation specialising in the management of energy and environmental programs on behalf of the central government, the European Union and the International Energy Agency. In addition to knowledge and expertise, Novem also offers various forms of financial support. Novem cooperates with the business world, not-for-profit organisations, governmental bodies and research institutions.

More information on Novem is available at the following website: http://www.novem.org/novem/home.htm

Incentives

Third Paper on Energy

This document recommends a 33% energy efficiency increase for the and a 10% Renewable Energy component for the Netherlands by 2020.

Kyoto protocol

The government of the Netherlands committed to a 6% reduction in greenhouse gas emission by 2010 with 50% (25 Mton) of that coming from international measures and the other 50% within the Netherlands itself.

Background on the GAVE Programme

drawn from "Working Together on Energy for the Future: Inventory and analysis of new gaseous and liquid energy carriers" & "GAVE: Gaseous and Liquid Energy Carriers" both published by Novem B.B. in cooperation with the Ministry of Housing, Spatial Planning & the Environment and the Ministry of Economic Affairs of the Netherlands.

In order to promote the market introduction of new gaseous and liquid energy carriers, a sum of NLG 40 million was reserved by the Netherlands government from the CO_2 reductions funds for a programme consisting of three phases: an inventory and field survey; a long-term research programme; and the development and demonstration of promising options. The three phases will take place over a 10-year period starting in 1998.

The inventory and field survey was completed in December of 1999 so that a decision could be made on the continuation of the other scheduled phases. The objective of the first phase was to draw up an inventory of the prospects for liquid and gaseous fuels. Where relevent, and certainly with respect to biomass, the market prospects and cost-effectiveness was compared with that of electricity generation and other reference situations. The results of Phase I were used to determine whether or not the next phase will be carried out, and if so, which direction it will take.

The inventory phase was carried out by Novem, at the request of the ministries of Health, Spatial Planning & Environment and Economic Affairs. The GAVE activities were overseen by a manager, Mr Eric van den Heuvel of Novem and guided by representatives of the organisations involved. During this phase, an inventory and evaluation of various technological options was made so that preliminary priorities could be

given to these options. The needs of the parties involved was also considered. Based on the above, the two ministries then made a go/no-go decision on the progress and content of Phases 2 and 3.

Both technological aspects, as well as environmental, economic, social and communicative aspects were included. The following paragraphs provide a discussion of these aspects in greater detail.

Objective and envisaged results

The main aim of Phase I was to form a clear basis for a decision by the two ministries concerning the possible follow-up phase, which will be geared to realising large-scale demonstration projects.

When the decision is taken, it is important that the industrial sector and the other parties involved support the decision, and that suitable plan for realising these demonstration projects will be based on the results of analyses performed during Phase I and the discussions with the stakeholders.

A decision must also be reached on the further development of those options that are promising but not yet fully developed, as well as the most suitable support that can be provided beyond the scope of the GAVE programme.

The envisaged results for Phase I were:

- Insight into the technical, financial, ecological and international dimensions and prospects of the potential conversion and product chains, compared to other options for sustainable energy and reduction in CO_2 emissions (including CO_2 storage);
- Insight into the non-technical aspects of the product chains and also, with regard to using biomass as fuel, the availability of biomass;
- Insight into the safety aspects of the various options;
- A list of technical options according to priority, based on the results of the various analyses;
- Insight into the possibilities of performing the pre-competitive study, to be carried out within the framework of the Dutch/Japanese partnership, for the possible second and third phases of this programme;
- A list of criteria to serve as the basis for making go/no-go decisions on the implementation of Phases 2 and 3. This criteria list will be drawn up in consultation with both ministries;
- The commitment of the industrial sector and other parties to participate in the further development of technological options which may be the subject of Phases 2 and 3;
- A detailed development plan for Phases 2 and 3, including explicit objectives and expected results for both phases, the plan of approach being used to realise these objectives, time span, organisational structure, evaluation criteria and proposed communication activities;
- Insight into social support for the developments envisaged in this programme;
- Insight into the way in which the proposed projects for Phases 2 and 3 can be financed by using the possibility of linking up to other sources of funding;
- Communication with, and transfer of knowledge to, relevant organisations and companies.

Approach

This phase comprises the inventory and evaluation of the technical options and a survey of the long term needs of the Dutch parties involved.

To achieve this, the following analyses will be performed.

a) Inventory and analysis of the technical options.

b) Methodological analyses.

c) Socio-economic analyses.

d) Integral analysis.

Inventory and analysis of technical options

The inventory and analysis of the technical options will determine the current state of the art and their potential contribution to the CO_2 and sustainable energy objectives. To this end, an inventory must be made of the existing technical options (e.g. using a Quick Scan based on available information and a SWOT analysis), and compared to (reference) options. The technical performance of the following options can then be determined.

Options based on fossil fuels for the production and application of new liquid and gaseous energy carriers.

Biomass options for the generation of heat and electricity.

Biomass options for producing and using new liquids and gaseous energy carriers.

CO_2 storage options.

Throughout the analysis, performance can be explicitly described in terms of potential reductions of fossil fuel consumption and CO_2 emissions. The technical environmental effects (including Nox, dust emissions, production waste and residues) will be described, as well as the economic performance of this option (in terms of cost-effectiveness with regard to sustainable energy and CO_2 reduction). A preliminary priority ranking can then be given in terms of technology, economics, and the environment. It is also important to identify the main bottlenecks in development and suggest possible solutions. It is vital that the analysis is based on a chain approach, examining not only the core of the technology, but also the preliminary and

final stages of developments. When evaluating the performance of biomass-based options, the availability and suitability of the fuel play a significant role. The performance for liquid and gaseous fuel options are also compared to that of other biomass applications. The preliminary and final stages can also play a role (e.g. infrastructure aspects in using methanol or hydrogen as fuel). An overview of the safety aspects must also be made.

Methodological analyses

Not all technological options have reached the same level of development. Nevertheless, a clearly defined comparative parameter is needed. A method of comparison must be used to analyse the various options. In view of the limited duration of Phase 1, a new method will not be developed, but existing methods, such as LCA method, will be used in the financial, environmental and technical analyses. To ensure comparison of the financial analysis, a common denominator must be found between those technologies that are still in a developmental stage (such as the HTU process) and those that are much further developed (ETBE from bio-ethanol). Here, the expertise of cost engineers in the chemicals sector will be valuable in drawing up a workable and comparable investment estimate. Information on the comparative parameter should be available as soon as possible in Phase 1 as this methodology will be used in the technology analysis.

Socio-economic analyses

Socio-economic analyses are defined as:

A non-technical SWOT analysis to implement a technical option;

A three-layer assessment of the availability of biomass, representing the global, European and national context. At a global level, the possible conflict between sufficient biomass and food production could play a role. At the European level, the availability of biomass for the Netherlands must be viewed in the context of the DE objectives of other European countries and the European Union. At a national level, using technology, legislation, and spatial planning to link several objectives can play an important role;

Criteria \ Analyses	Technology and Risk Analysis	Emissions Analysis	Cost / Benefit Analysis	Macro- and Socio-Economic Analysis	Stakeholder Support Analysis	Replication Potential Analysis
Technology development phase	■					
Breakthroughs required	■					
Viability of commercialisation	■					
Abs. contribution to CO_2 emission red.		■				
Ability to realise trend reversal		■				
Direct costs & benefits (avoided CO_2-eq.)			■			
Indirect costs & benefits (economic side-effects)				■		
Feedstock price stability			■			
Support from government End-users/NGO's Suppliers					■	
Degree of other environmental effects (soil, water, air emissions)		■				
Applicability abroad						■

■ Analysis performed to assess criteria

An analysis of requirements of the parties involved in new liquid and gaseous energy carriers. This will probably include more parties than the aforementioned stakeholders, who will mainly be approached about energy-related, technical and industrial interests. Parties could be organisations such as the Consumer Organisation, ANWB (Royal Dutch Touring Club), BOVAG (Association of Car Dealers and Garage Owners), plus environmental and nature conservation associations. In other words, organisations that are important in terms of establishing social support.

The socio-economic analyses indicate the non-technical risks and opportunities within the technical options and the direction from which solutions could be found.

Integral analysis

In order to evaluate the results of the technical and socio-economic analyses, an integral analysis based on the aforementioned analyses will be performed at the end of Phase 1. The objective is to provide a foundation for the possible step towards Phases 2 and 3. Multi-criteria analysis methods will be used. The long-term research programme in Phase 2, and the demonstration of several pilot projects in Phase 3, must be geared to technologies with the best chances of success.

The analyses will generate a wide range of data from which the various options can be evaluated. In most cases, no single option will score better than any of the others on all fronts. The technical, environmental, financial and non-technological factors must be evaluated. By using different forms of approach in the integral analysis (e.g. emphasising either technical factors or economic factors), we can establish which options score better than those already in progress, and which technical options should be top of the priority list in terms of overall factors.

Summary of methodology

Options with good prospects will be assessed and compared with existing energy sources on the grounds of their cost-effectiveness, conservation of fossil fuel and reduction in CO_2 emissions. In the assessment other than technological, economical and environmental aspects are important. The following aspects play a role in this regard:

- Technological
  What are the technological features of the option?

- Economical
  What is the viability?

- Environmental
  What are the environmental effects?

- Market potential
  Can the technology achieve a substantial reduction in fossil fuels and/or CO_2 emissions?

- Safety
  Which safety factors would play a role in the production and use of the energy carrier if it were to be implemented on a large scale?

- Support
  Is the industry prepared to invest? And what is the support of e.g consumer and environmental organisations?

- Infrastructure
  What modifications to the infrastructure are required?

- Availability
  For example, is sufficient biomass available?

- Job opportunities
  Does the technology directly or indirectly create jobs?

The technologies will be assessed and ranked on grounds of the above aspects. Naturally, the analysis takes into account the developmental stage of the new technologies, so that a fair comparison can be made.

Part 1 - Perspective of the Dutch Government (continued)

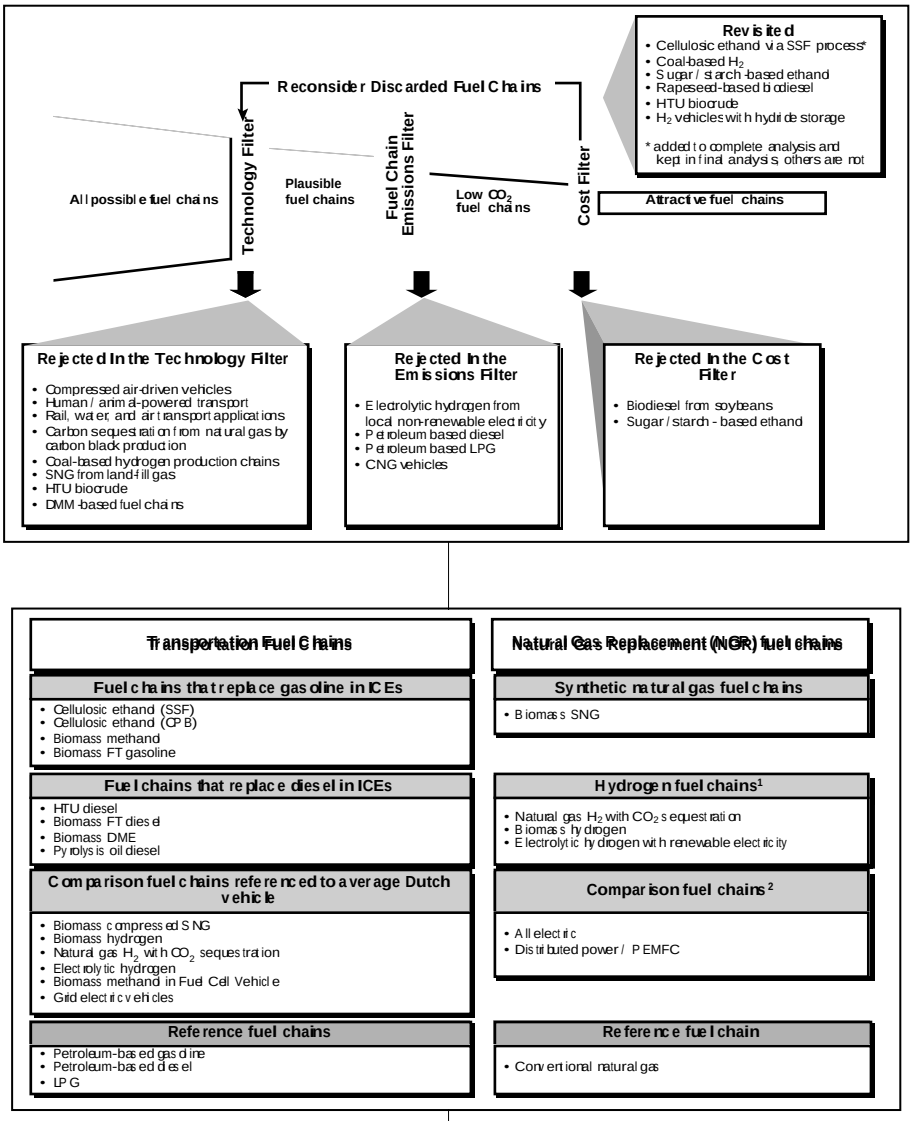
Arjan de Zeeuw
mailto:a.de.zeeuw@novem.nl

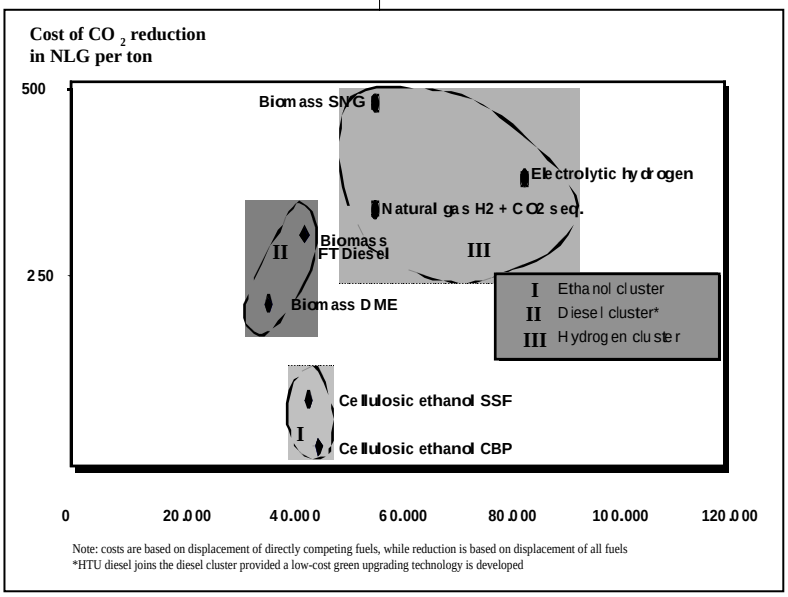
Results of Phase 1

The most promising energy production chains were identified as biomass based and fossil fuels with CO_2 sequestration. Transportation fuel clusters have a lower cost whereas the natural gas replacement cluster has a greater CO_2 reduction potential. Short term solutions were identified as well as long term perspectives. The stakeholders have expressed an interest in committing to the proposed solutions which involves a transparent process with market involvement.

Biomass based solutions include the replacement of gasoline with ethanol from cellulosic biomass. This option was shown to be attractive for CO_2 emission reduction.

Ethanol fits into the existing infra-





structure with blending experience in both the Brazil, Canada and USA. Pure ethanol requires very few changes in the current infrastructure. Various production technologies are possible with an estimated laboratory scale cost of 100 NLG/ton and a demonstrated cost of 130 NLG/ton. Sugar beet based technology can be used in the demonstrations but is not economical for full-scale production. The ethanol option is relatively unknown in the Netherlands and demonstration of the whole production chain will need broad collaboration.

Other gasoline alternatives appear to be two to three times more expensive on a NLG/ton CO2 equivalent avoided basis than biomass derived ethanol. CO2 avoidance with diesel-type fules appears to be significantly more expensive than for gasoline-based fuels. DME appears to offer the least expensive alternative to diesel at about 240-250 NLG/ton. FT diesel would cost about 330 NLG/ton but has a greater CO2 reduction potential.

The costs of other alternative fuel chains that cannot use the existing infrastructure are significantly higher. The end-use technology significantly increases the cost and the CO2 reduction potential is not significantly higher.

Final Recommendations to the Ministries

- Start-up a demonstration facility in both the transportation and natural gas sectors to reduce CO2 emissions.
- Draw up the preconditions to investigate the optimal application of biomass and stimulate (i) the whole chain approach and the international orientation of industrial stakeholders and research institutes, (ii) active involvement of public players and develop the lay-out and content of a new program in a short preparation period.

Coming activities

- industrial parties have been asked to present their demonstration plans;
- initiation of a study to evaluate the long-term world-wide availability of biomass;
- development of a program layout and content;
- developent of preconditions for project selection;
- investigation of the potential for international collaboration activities.

Part 2 - Nedalco's Activities

Hans Niessen
mailto:j.niessen@nedalco.nl

Present Situation

The Netherlands and Nedalco are currently not in the fuel alcohol market. Although Nedalco is the largest producer of potable alcohol in Europe from sugar beet, cane molasses and grain.

Nedalco supplies 130 thousand m^3 of the European market 2000 thousand m^3 annual production. This production represents a leading market share in the food grade alcohol market and an intermediate position in the industrial grade alcohol market. Nedalco has locations in Belgium, Denmark, Germany, Italy, Netherlands, Spain and UK.

More information on Nedalco is available at their website:
http://www.nedalco.com

Research Objectives

Nedalco has the following research objectives:

- To develop route(s) from multiple feedstocks to fuel alcohol;
- These route(s) should be economically viable without subsidy within 10 years;
- The ethanol should have a production cost of 0.17-0.25 USD/L;
- Reduce carbon dioxide emissions.

Development Constraints

Sufficient finances must be generated for development and the development risk must be under control i.e., low risk of failure (financial, technological). A step by step approach will be used to mitigate the risk.

The initial step was to look at the available proven process technology, feedstocks and markets for by-products. This was followed by an evaluation of available production facilities and pilot/semi-production facilities.

Development Program

The Nedalco program has two main elements:

1) Bioethanol project

This project has a market to market approach in that involves the conversion of an existing MTBE plant to a ETBE process. There already is a dedicated customer for the ETBE to be added to gasoline. The facility will represent a semi-production size facility producing 3 million lites of ethanol annually.

2) Additional projects

These will include basic research by research institutes and a semi-pilot production facility at Nedalco and possibly at a number of alternative locations. The products produced from these facilities will be marketed through the bioethanol project.

Conclusion

It is our belief that fuel ethanol will be economically viable within 10 years. A step by step and market approach with partnerships is required to be successful.

CANADA

William Cruickshank
Natural Resources Canada
mailto:wcruicks@nrcan.gc.ca

Production of Fuel Ethanol from Lignocellulosic Feedstocks in Canada

Natural Resources Canada's research program on ethanol from biomass is supported by PERD through the Bioenergy Development Program. The objective of the program is to develop technologies and integrated systems for the cost-competitive production of ethanol and value-added products from lignocellulosic feedstocks. The issues that are driving this program are environmental issues such as the GHG's through the Kyoto Protocol and agricultural diversification. The R&D projects for this program are contracted-out to interested parties on a cost-shared (25% minimum) basis. The annual research budget for this program is 1 million Can$. The active projects are:

Feedstocks/Pretreatment:
Steam Pretreatment of Softwood Residues - University of British Columbia - Dr. Jack Saddler

Hydrolysis:
Improved Cellulase Enzyme Hydrolysis of Biomass Feedstocks Iogen Corporation - Dr. Theresa White

Fermentation:
Pilot Scale Fermentation of Pentose Sugars - Tembec Inc. - Dr. David Cameron & Mr. Bob Benson

Coproduct Development:
Biorefining of Biomass Feedstocks for the Production of Ethanol and Value Added Co-Products - Kemestrie Inc. - Dr. Esteban Chornet

Integrated Biomass:
Operation of a Demonstration Plant for Ethanol Production Producing Fuel Ethanol from Biomass - Iogen Corporation - Mr. Patrick Foody Jr.

Conclusion:
Cooperation and cost sharing between Natural Resources Canada, Canadian Industry and Academia has enabled the development of state-of-the art biomass-to-ethanol technology. Participation in IEA Task 26 provides and ideal mechanism for Canada to cooperate internationally with other countries who share the same objective of making biomass ethanol a commercial reality.

AUSTRALIA

Neville Pamment & Zhou, B.*
Department of Chemical Engineering
University of Melbourne
mailto:pamment@chem.eng.unimelb.edu.au

"Hemicellulose-to-Ethanol fermentations - How far have we come?"

Neville agreed to present an overview of the advances in hemicellulose-to-ethanol fermentations from the point of view of commercialisation and looking at the international picture, especially developments in the USA. The talk focussed primarily on the following recombinant high ethanol producing strains:

1) *Escherichia coli*

Ingram, Univ. of Florida
K011 - chromosomal integrant
LY01 - integrant with high ethanol tolerance

FBRI, USDA, Peoria
FBR series - stable plasmid strain

2) *Saccharomyces cerevisiae*

Ho et al., Purdue
1400 pLNH32,33
LNH-ST - chromosomal integrant (various patents)

3) *Zymomonas mobilis*

Zhang et al., NREL
CP4 (pZB5)
ZM4 (pZB5)
C25 chromosomal integrant (xylose utilising)
AX101 xylose/arabinose utilising

Current Levels of Fermentation

Neville then proceeded to compare some of the best recent data obtained by the various groups for batch fermentations under "real-world" conditions (i.e., data obtained with native, as opposed to synthetic, hydrolysates, commercial nutritional supplements and in the absence of antibiotics) Some issues to be resolved were highlighted, including:

- the relatively low rate of xylose utilisation (compared to glucose) by all strains. (Efforts to remedy this are underway in at least two labs)
- the problem of galactose sparing
- cost and supply issues associated with medium nutrients
- the potential for genetic manipulation work to reduce the requirement of organisims for complex nutrients
- the need for further work to assess the feasibility of cell recycle in repeat batch culture in hydrolysates
- the need for more careful documentation of strain maintenance and inoculum preparation procedures
- the desirability of comparative studies of the candidate organisms under closely comparable cultural and analytical conditions on a range of substrates

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DENMARK

Birgitte Ahring* & Anne Belinda Thomsen
Technical University of Denmark
mailto:bka@ucla.edu

The Danish Concept of Bioethanol Production from Biomass

Birgitte discussed the current Danish vision of a bioethanol production

process. This focused on converting wheat straw into ethanol via a wet oxidation pretreatment, enzymatic hydrolysis and thermophilic anaerobic fermentation

Potential products & byproducts from bioethanol production from biomass

Sugars: glucose, xylose, arabinose

Fermentation products: ethanol, xylitol, fatty acids, lactic acid, methane

Fibre products: plastic composites, fibre board, animal food fibres, hemicellulose plastics

Wet oxidation

Wet oxidation is the reaction of molecular oxygen with an organic component taking place under aqueous conditions and at elevated pressure and temperature.

-R- + O2 -> Products + CO_2 + H_2O + Energy

Hemicellulose solubilization

Thermophilic anaerobic bacteria for production of bio-ethanol from lignocellulosic biomass

Advantages

- Ferments both hexose and pentose sugars
- Produces ethanol at boiling point of ethanol (78 C)
- Low risk of pathogenic contamination at high temperature
- Produces thermostable enzymes

Disadvantages

- Low ethanol tolerance
- Production of by-products
- Low substrate tolerance
- Addition of co-substrates (yeast extract)
- Limited knowledge of biochemistry and genetics

FINLAND

Liisa Viikari
mailto:liisa.viikari@vtt.fi

VTT has been previously profiled in issue 4 of the IEA Task 26 newsletter which is available at the IEA Bioenergy website. VTT Biotechnology has primarily pursued the fermentation and enzymatic hydrolysis elements of biomass conversion for ethanol and chemicals through the following: enzyme research and development; partial and total hydrolysis of lignocellulosics and metabolic engineering for more efficient fermentation.

Enzyme Research and Development

There are five main areas of interest in this major category of VTT's biotechnology research. These are: improvement or development of new cellulolytic enzymes; hemicellulases and oxidases; combinations of enzymes; molecular biology of enzyme secretion and mechanisms of gene expression.

VTT Biotechnology has concentrated their efforts on the enzymes associated with 10 species of microorganisms (see Table) for a number of applications. Most of the work related to bioconversion is with the cellulolytic enzymes (Endoglucanase I to V and Cellobiohydrolase I and II) of Trichoderma reesei..

For example the cellubiohydrolases of *Trichoderma reesei* i.e., CBHI (Cel7A) and CBHII (Cel6A) have been characterized with regard to their stucture, biochemical and biophysical properties and undergone protein engineering to explore their catalytic domain, linker protein and cellulose-binding domain (CBD). These studies have provided valuable information on the mechanisms of these enzymes to hydrolyze cellulosic substrates.

Partial and Total Hydrolysis of Lignocellulosics

This area of research has concentrated on the modification of fibres, combined pretreatment techniques and optimization of hydrolysis by new enzymes.

Metabolic Engineering

Examples of projects that have included metabolic engineering are: diacetyl non-producing brewer's yeast (patent filed in 1989 and ready for industrial use), xylitol production (patent filed in 1990, process optimization still needed), xylose fermentation (patent filed in 1990, basic research still required to obtain theoretical yields), and a major metabolic engineering program that ran from 1996 to 1999. The latter included the development of techniques, engineering major carbon fluxes of yeasts, balancing glycolysis and pentose phosphate pathways, xylose fermentation,

Organism	Enzyme
Trichoderma reesei	Endoglucanase I-V Cellobiohydrolase I & II Xylanase I & II β-Xylosidase α-Arabinosidase α-Glucuronidase Acetyl xylan esterases Mannanase
Aspergillus oryzae	Xylanase I & II Acetyl mannan esterase Feruloyl esterase
Aspergillus fumigatus	Xylanase I & II
Aspergillus niger	Galactanases Polygalacturonidase
Aspergillus terreus	α-Arabinosidases

Penicillium simplicissimum	α-Galactosidases
Bacillus circulans	Xylanase
Bacillus subtilis	Mannanase
Phlebia radiata	Lignin peroxidase Mn-peroxidase Laccase
Coriolus versicolor	Laccase

redox and energy balancing. There were patents filed in 1997 and 1998 associated with major improvements in glucose and xylose fermentation. The program looked at non-conventional yeasts, bacteria as well as brewer's yeast and filamentous fungi.

SWEDEN
Guido Zacchi*, Mats Galbe, Kerstin Stenberg, Charlotte Tengborg
Chemical Engineering 1
Lund University
mailto:guido.zacchi@kat.lth.se

Fuel Ethanol from Softwood
Process Development using a PDU

Guido discussed the Process Development Unit (PDU) at the University of Lund and some of the recent research findings using the PDU.

Process Development Unit (PDU)

The PDU allows us to evaluate the following process units:

- Batch acid hydrolysis with the ability to use a temperature range of 160-230 C and test scale-up by a factor of roughly a factor of 5 (10 L & 2 L vessels).
- Batch, fed-batch and continuous enzymatic hydrolysis over a temperature range of 40-90 C with two vessel sizes for scale-up trials (20 & 40 L).
- Batch, fed-batch and continuous SSF fermentation with a temperature range of 35-80 C and three different vessel scenarios (100 L, 3*20L, 2*5L).
- Separation will be accomplished through both a centrifuge and a filter press.

4. Recovery will be through a 20 L evaporation and a distillation unit.
5. Analysis is through an HPLC and TOC.

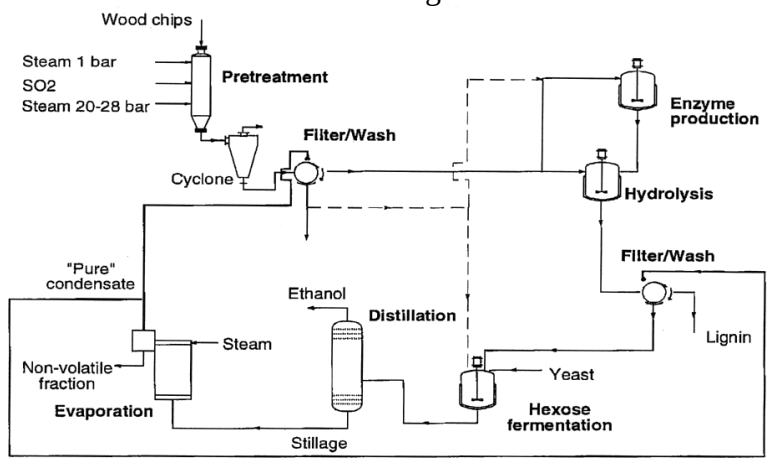
The PDU provides enhanced knowledge of the material balances, flow-stream composition, characterisation of products/by-products and waste streams, and the ability to adapt micro-organisms to continuous operation. Thus providing a framework for process optimisation. The PDU also needs to have a great deal of flexibility as it will be required to evaluate various raw materials (cellulose & starch), various process steps (separate & integrated) and various process configurations (SSF, SHF, multi-stage acid hydrolysis, recycling of process streams, etc.).

Softwood to Ethanol Process Research

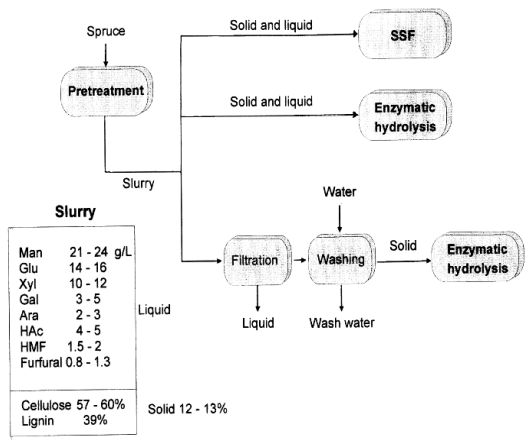
Process Scheme Comparison

Two general process schemes have been compared i.e., Separate Hydrolysis and Fermentation (SHF) and Simulataneous Saccharification and Fermentation (SSF) for two softwood species.

Process Configuration



Processing schemes



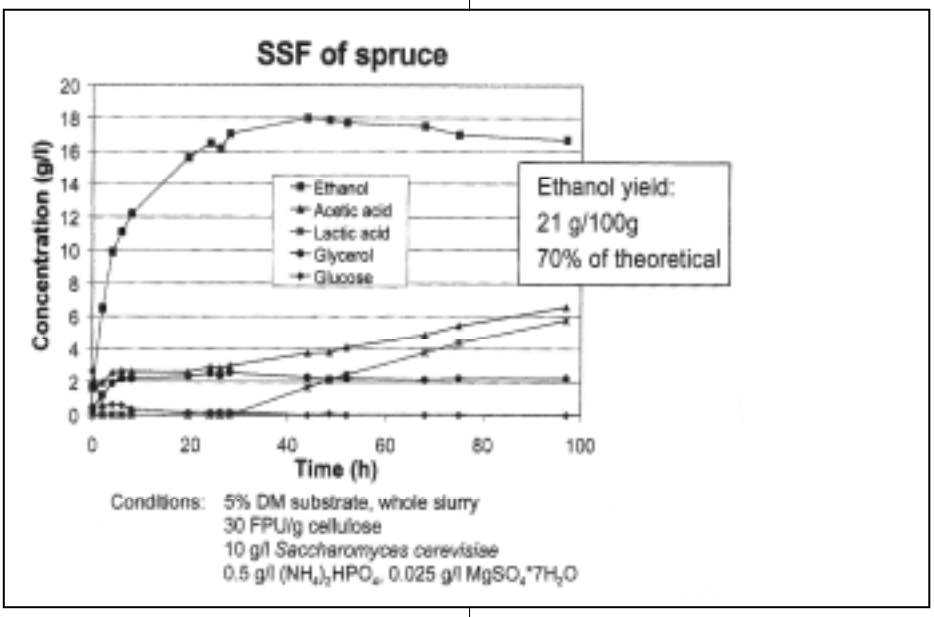
Substrate	Ethanol Yield (% of theoretical)
Willow, SSF	85
Willow, SHF	85
Spruce, SSF	70
Spruce, SHF	58

SHF = separate enzymatic hydrolysis and fermentation
SSF = simultaneous saccharification and fermentation

Cellulose Conversion Rates using Various Fractionation Schemes

Substrate	Cellulose conversion in relation to reference
Whole slurry	1.00
Washed pre-treated spruce	1.32
+ prehydrolysate and washing water treated with laccase	1.02
+ prehydrolysate and washing water treated with Ca(OH)2	1.04
+ fermented prehydrolysate and washing water	1.38

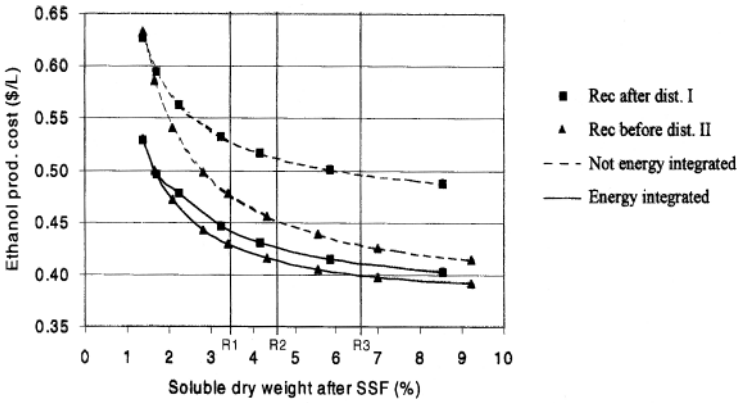
SSF Fermentation of Whole Slurry



Various Water Recycling Schemes

Four water recycling schemes have been evaluated and as shown in the figure the integration of energy or recovery of energy within the process reduces the cost of producing ethanol substantially. There was also a significant difference between recycling before and after the distillation. Particularly in the case where the energy is not integrated there was a major advantage to recycling the water before the distillation.

Water Recycling Schemes



USA
Quang Nguyen*, Cynthia Riley, John Sheehan and Robert Wooley
National Renewable Energy Laboratory
mailto:quang_nguyen@nrel.gov

Bioethanol Process Development Strategies and Implementation: A Perspective

Bioethanol Process Technology Development Path

Quang outlined strategies and methods NREL uses to help industry develop and commercialize bioethanol process technology. These include the development of a listing of opportunities and needs, strategic objectives, a portfolio of technologies to satisfy the objectives, a stage gate process to manage technology development and assist industry in commercialization. Each of these aspects was discussed in more detail.

Opportunities and Needs

Opportunities

General support of bioethanol as a remedy to environmental and rural economic problems (farming and forestry sectors) (near to mid term)

Phase out of MTBE in many states (near to mid term)

Conversion of unused biomass residues to value-added products (near to mid term)

Needs

Biomass residue disposal (near to mid term)

Reduction in dependence on imported crude oil (mid to long term)

Green house gas reduction (mid to long term)

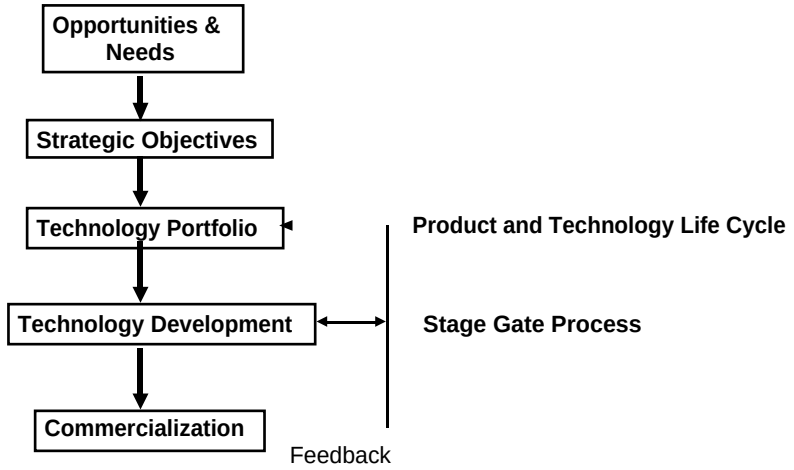
Strategic Objectives for Bioethanol Technology Development

Technologies must be developed to take advantage of opportunities and meet the needs identified (i.e., customer and time focussed)

Develop a Technology Portfolio which includes near term technologies and mid to long term technologies.

Leverage and integrate development efforts in various stages.

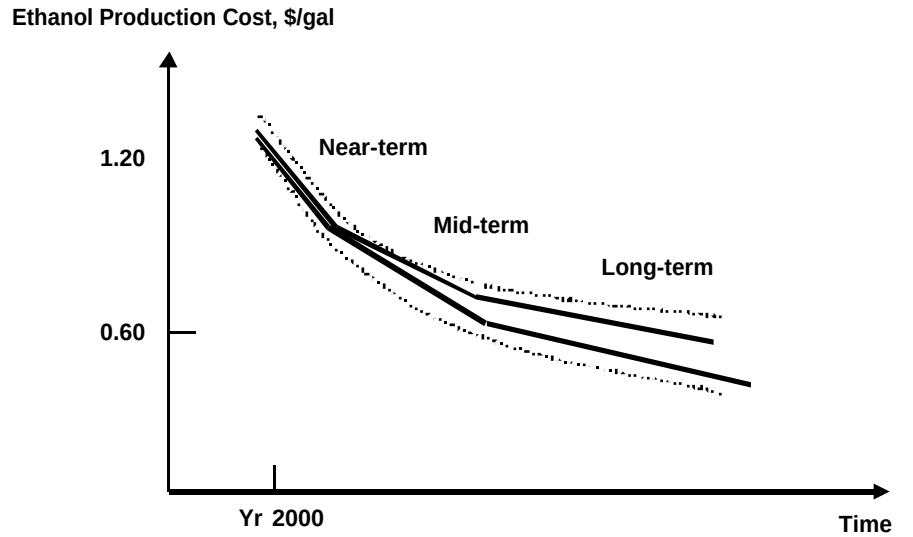
Bioethanol Process Technology Development Path



Product and Technology Life Cycle

There is a characteristic life cycle associated with the research, development and deployment of any technology. There is also a parallel cycle of market penetration. In the near-term the technology is in its infancy with the original ideas being further investigated and developed.

Bioethanol Production Cost Reduction Path



Bioethanol Production Cost Reduction Path

A Balanced Technology Portfolio must include Strategic Leaps (i.e., major technical breakthroughs and innovations) and Incremental Improvements. Technical breakthroughs generally require fundamental knowledge of the characteristics of processes or materials.

Near to mid term opportunities in niche feedstock in many areas of US include agricultural residues (corn stover, bagasse, straw), forest residues and muncipal solid waste.

As an example, a technology development path for conversion of softwood residues to ethanol was proposed.

Near-term hydrolysis technologies include the use of two-stage dilute acid hydrolysis or concentrated acid hydrolysis.

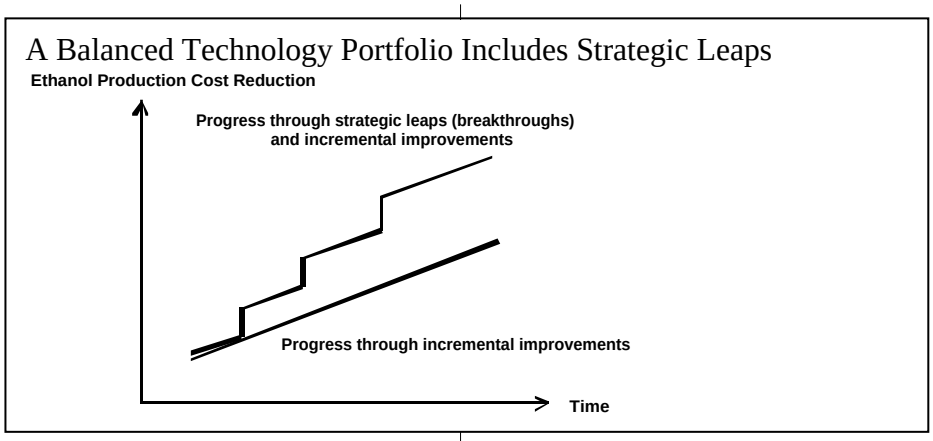
Mid-term hydrolysis technologies include the use of: co-current (or countercurrent) dilute acid pretreatment followed by enzymatic cellulose hydrolysis; enzymatic cellulose hydrolysis with increased specific enzyme activity, improved thermal enzyme stability and improved enzyme utilization.

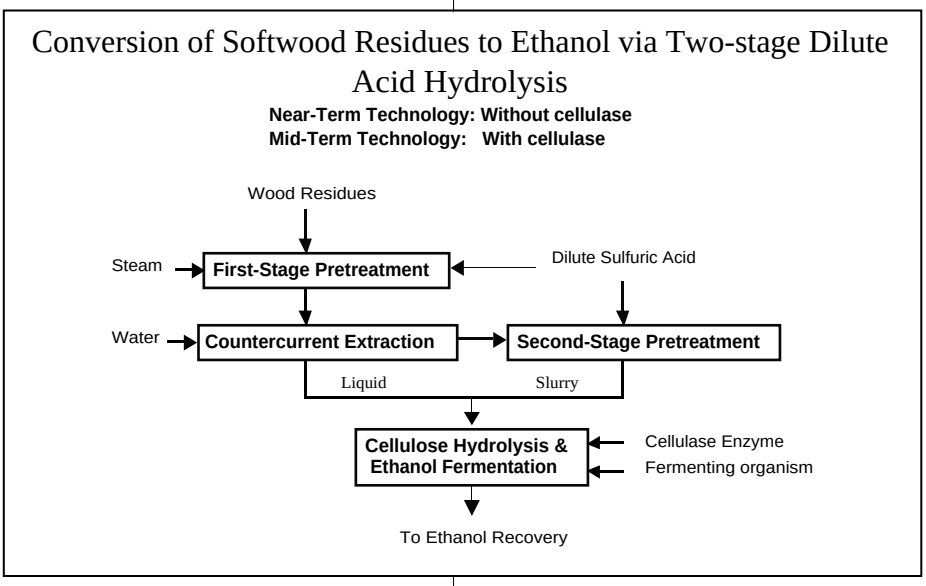
Example: Comparison of Single-stage and Two-stage Dilute Acid Hydrolysis of Softwood Forest Thinnings to Sugar

Hydrolysis type	Single Stage Sugar Yield (%)	Two Stage Sugar Yield (%)
Dilute Acid	44	65
Dilute Acid plus Enzyme	75	82

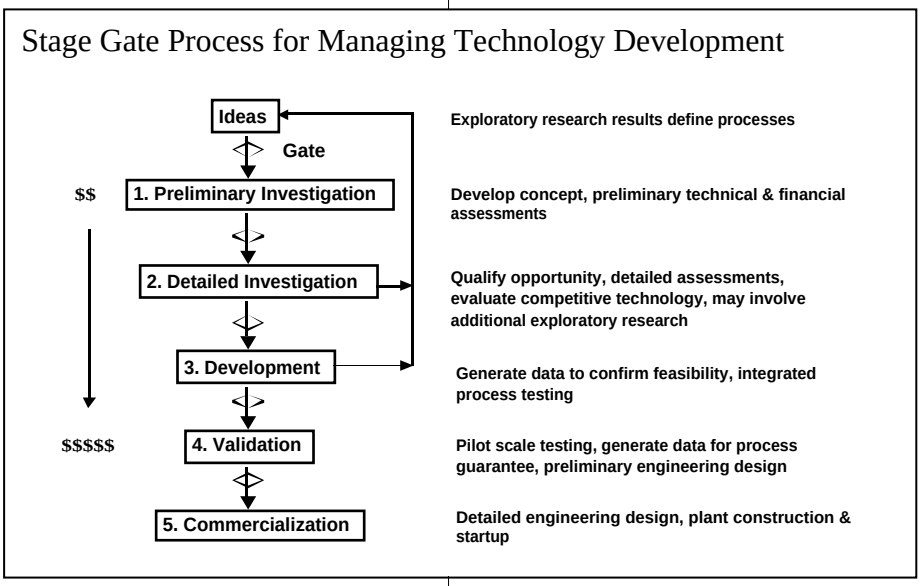
Stage Gate Process for Managing Technology Development

Goals of "Stage Gate" Process





- Better home work up-front i.e., focus on early stages of development to select the most viable technologies.
- Quality of decision and execution will result from better prioritization, completeness and standard metrics.



- Strong customer/competitive technology orientation

- Fast-paced, parallel and multi-functional activities such as technical, economic, environmental, legal, etc.

Function of Gates:

Evaluate accomplishments using established criteria

Make informed decisions on future actions of projects

USA
Charles Wyman
Dartmouth College
mailto:charles.e.wyman@dartmouth.edu

Changing Research Needs to Build a Major Bioethanol Industry

Although we have come a considerable distance in moving the concept of converting lignocellulosic feedstocks to ethanol into a technical reality, the barriers of demonstration and commercialization are significantly different and in many ways more challenging. This presentation outlines some of those challenges and suggests ways to reduce or overcome them.

Some considerations in financing a new project include:

- Financing considerations
- Feedstock cost and availability
- Product and market
- Technical position, competitiveness, and demonstrated performance
- Costs and construction contract
- The site
- The team
- Risk
- Scrutiny

An example of one of these considerations is the impact of feedstock composition variations on cost. As the percentage of carbohydrate polymers in the feedstock increase from 50 to 70 the cost of the ethanol drops almost linearly from roughly 1.75 $US/gal to roughly 1.25.

One favored method for reducing risk is to use successive scale-up of a process. However, scale--up presents its own set of challenges:

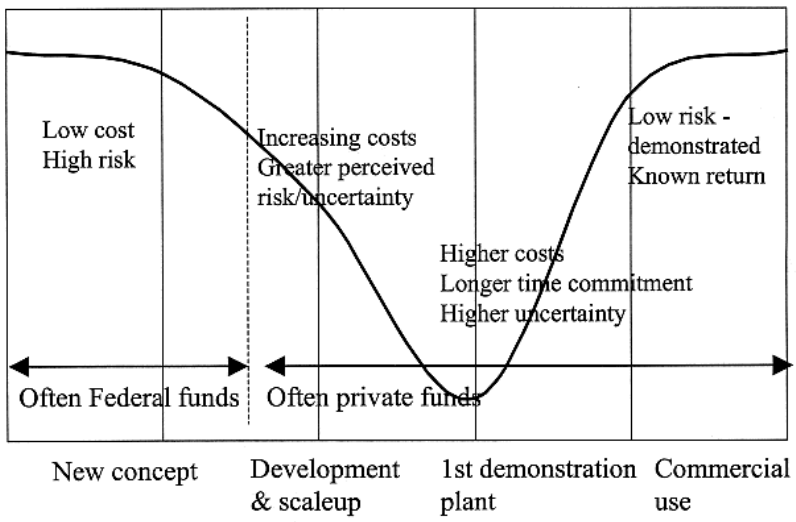
- many financiers are reluctant to scale up by more than a factor of ten
- scaling is very expensive in capital and operating costs
- takes a long time to complete
- difficult to impossible to finance because of risk, time required and cost

One method used to assure or guarantee to financiers that the costs and risks associated with technology scale-up are addressed is through a successive layering of contingencies. A normal contingency is applied to the core technology. Then in successive layers a performance margin, followed by extra equipment and extra contingency are applied.

There is generally a pattern (see Figure) of cost, risk and type of funding associated with the research, development and commercialization of any new technology. In the early stages the costs are relatively low, risk high and the funding comes from govemment sources. As development proceeds the costs begin to rise, the perceived risk is greater and often private sources of funding begin to take over. Once the technology is commercialized the return on investment is returned as the risk is relatively low and the return is known. The relative commercial costs are asymptotically reduced with time through the learning curve.

The presentation was concluded with the following thoughts:

- Bioethanol technology is poised for commercialization
- The road to commercial use is difficult
- Commercial use will feed incremental advances
- There is a need to significantly advance the technology to have a greater impact
- There is a need to develop a solid basis to support improvements and their applications
- It is important to work together to realize this important opportunity. ♣



The Valley of Death for New Technology

FUTURE WORKSHOPS/SYMPOSIA
(Mark these in your diary!)

July, 2000

ISAF XIII
International Symposium on Alcohol Fuels
"Implementing the Transition to a Sustainable Transport System"
Stockholm, Sweden
July 3-6, 2000

Local Organiser:
Lars Vallander,
Swedish National Energy Administration
e-mail:lars.vallander@stem.se
website: http://www.stem.se

December, 2000

IEA Symposium on Biomass-to-ethanol

Held within PACIFICHEM
Chemical Society Symposium
Honolulu, Hawaii
U.S.A.

Local organiser:
Jack Saddler
fax: 604 222 3267
mailto:saddler@interchange.ubc.ca

We encourage participants to contact us about hosting a meeting and suggesting a theme for workshops in 2000. ♣

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IEA TASK 26 COUNTRY REPRESENTATIVES

Country	IEA Task 26 Country Representative
Canada	Jack Saddler mailto:saddler@interchg.ubc.ca
Denmark	Birgitte Ahring mailto:bka@ibt.dtu.dk
Finland	Liisa Viikari mailto:liisa.viikari@vtt.fi
Netherlands	J.J. den Ridder mailto:J.denRidder@nedalco.nl
Sweden	Bärbel Hahn-Hägerdal mailto:barbel.hahn-hagerdal@tmb.lth.se

IEA BIOENERGY EXECUTIVE COMMITTEE (EXCO) MEMBERS

Country	IEA Bioenergy Country Representative
Australia	Dr. Stephen Schuck Steve.Schuck@bigpond.com
Austria	Dr. Josef Spitzer josef.spitzer@joanneum.ac.at
Belgium	Mr. Jean Renault jean.renault@cmlag.fgov.be
Brazil	Mr. Eugenio Miguel Mancini Scheleder mancini@mme.gov.br
Canada	Dr. Peter Hall phall@nrcan.gc.ca
Croatia	Ms Branka Jelavic bjelavic@sunce.eihp.hr
Denmark	Mr. Klaus Mandrup km@ens.dk
Finland	Professor Kai Sipila kai.sipila@vtt.fi
France	Mr. Pierre Ballaire pierre.ballaire@ademe.fr
Italy	Dr. Vito Pignatelli vito.pignatelli@casaccia.enea.it
Japan	Mr. Yoshitaka Tokushita tokushitayst@nedo.go.jp
Netherlands	Dr. Gerard Smakman G.Smakman@novem.nl
New Zealand	Dr. George Hooper George.Hooper@forestresearch.co.nz
Norway	Dr. Olav Gislerud olav.gislerud@forskningsradet.no
Sweden	Dr. Lars Tegner lars.tegner@stem.se
Switzerland	Mr. Martin Hinderling martin.hinderling@bew.admin.ch
UK	Mr. Richard Kettle richard.kettle@hend.dti.gov.uk
US	Dr. Raymond Costello raymond.costello@hq.doe.gov
EU	Mr. Kyriakos Maniatis kyri-akos.maniatis@bxl.dg17.cec.be

CHAIR OF FOREST PRODUCTS BIOTECHNOLOGY
FACULTY OF FORESTRY
UNIVERSITY OF British Columbia
#4041 - 2424 MAIN MALL
VANCOUVER, BRITISH COLUMBIA, CANADA
V6T 1Z4