IEA Bioenergy

Task 42 Biorefineries

Disruptive - Game changing Technologies

Ed de Jong

Avantium Chemicals

December 2015

Content of Slide Deck

1. Definitions and Examples of Disruptive Technologies
2. NIC's Disruptive Technologies Report
3. Why are Biofuels & Biobased Chemicals potentially Disruptive – Potential Impacts
4. Biorefineries necessary to make Biofuels & Biobased Chemicals disruptive
5. Disruptive (sub)technologies – Key Enabling Technologies
6. Conclusions
7. Annex 1: Scenarios NIC study

1. Definitions and Examples of Disruptive Technologies

Definition

Disruptive technology is a term coined by Harvard Business School professor Clayton M. Christensen to describe a new technology that unexpectedly displaces an established technology

What can be the driver of an "Unexpected Replacement"?

- Novel technology(ies)
- Legislation
- Consumer and/or NGO demands
- Depletion of current feedstocks

IEA Bioenergy

Task 42 Biorefineries

Biorefinery in relation to other Game Changing Technologies

1) Mobile internet
2) Automation of knowledge work
3) Internet of things
4) Cloud technology
5) Advanced robotics
6) Autonomous and near-autonomous vehicles
7) **Next-generation genomics**
8) Energy storage
9) 3D printing
10) **Advanced materials**
11) Advanced oil and gas exploration and discovery
12) **Renewable energy**

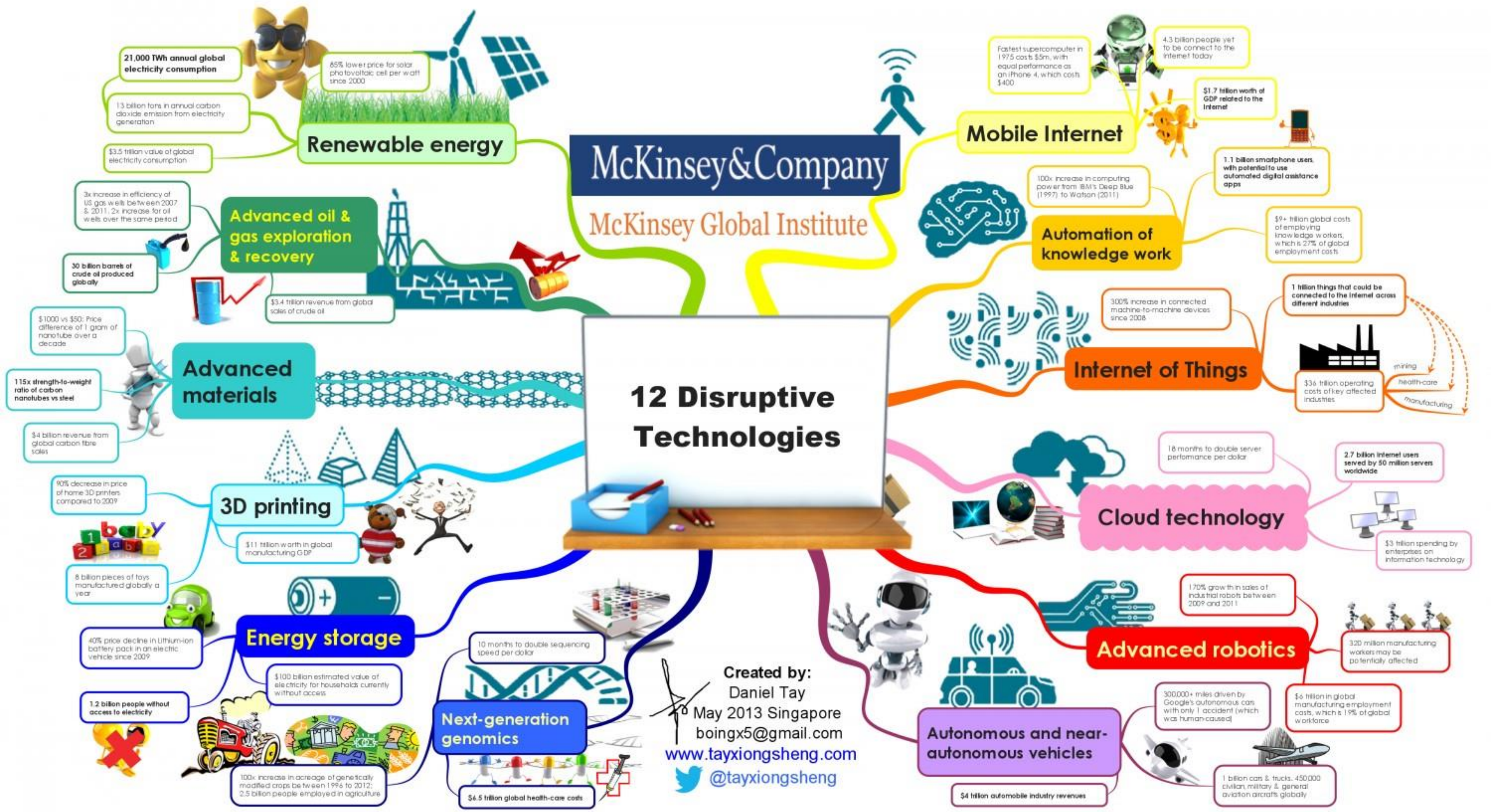
Manyika 2013 McKinsey Global Institute, 12 key technology developments

Green = Supportive; Red = Opposing; Blue= Neutral to the Biorefinery space;

IEA Bioenergy

Task 42 Biorefineries

Mind Map McKinsey's 12 Disruptive Technologies



The source of information in this Mind Map comes from http://www.mckinsey.com/insights/business_technology/disruptive_technologies

IEA Bioenergy

Task 42 Biorefineries

NIC's Disruptive Civil Technologies report

SRI[1] defined a **disruptive technology** as a technology with the potential to cause a noticeable - even if temporary - degradation or enhancement in one of the elements of **US national power**:

A. geopolitical
B. military
C. economic
D. social cohesion
E. Industrial

[1] SRIC-BI, National Intelligence Council report CR 2008-07 (http://www.globalbioenergy.org/uploads/media/0804_NIC_-_Background_Biofuels_and_Bio-Based_Chemicals.pdf)

2. NIC's Disruptive Technologies report

IEA Bioenergy

Task 42 Biorefineries

NIC's Disruptive Civil Technologies report

To support the development of the National Intelligence Council's Global Trends 2025[1], SRI Consulting Business Intelligence (SRIC-BI) was asked to identify six potentially disruptive civil or dual use technologies that could emerge in the coming fifteen years (2025)

1 SRIC-BI, National Intelligence Council report CR 2008-07 (http://www.globalbioenergy.org/uploads/media/0804_NIC_-_Background_Biofuels_and_Bio-Based_Chemicals.pdf)

IEA Bioenergy

Task 42 Biorefineries

NIC Study 2008

PROCESS FOR SELECTION OF DISRUPTIVE TECHNOLOGIES

Review of SRIC-BI knowledge base

Workshop

Step 1: Generate Ideas (wiki)

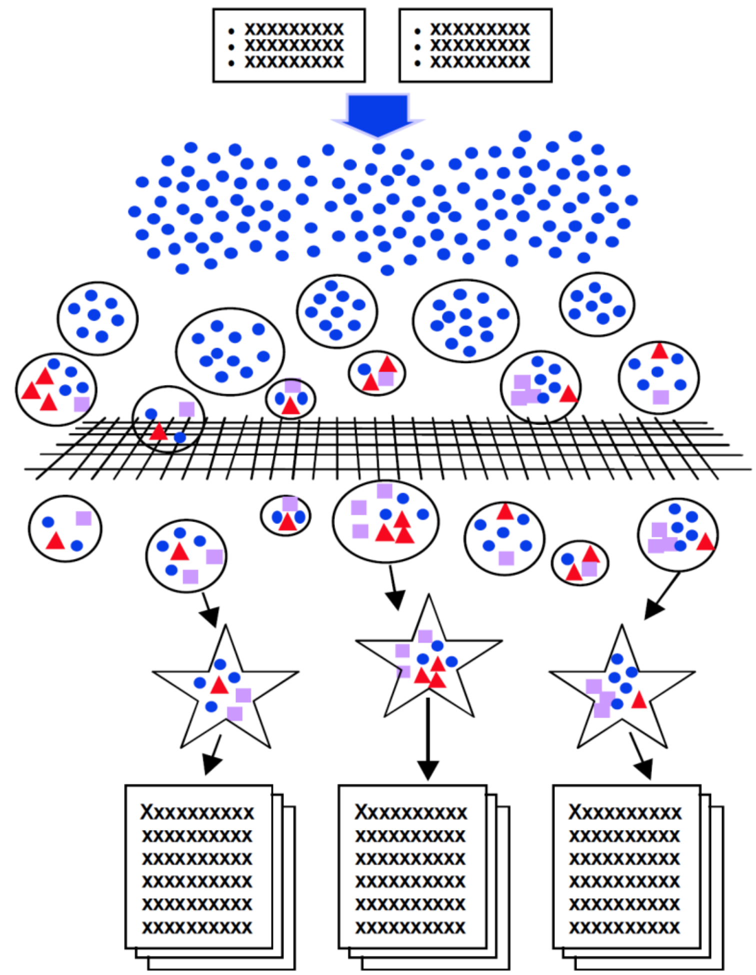
Step 2: Form Clusters

Step 3: Describe Technologies and Disruptions

Step 4: Screen Disruptive Technologies according to NIC-criteria

Step 5: Select Most Critical

Step 6: Create Disruptive Technology Profiles



Source: SRI Consulting Business Intelligence.

NIC Study 2008

BioFuels & Biobased Chemicals

SRI identified the following technologies as most likely to disrupt (enhance or degrade) US National Power out to 2025:

1. Bio-gerontechnology
2. Energy storage materials
3. Biofuels and biobased chemicals
4. Clean coal technologies
5. Service robotics
6. The internet of things

3. Why are biofuels & biobased chemicals potentially disruptive – Potential Impacts

Why are biofuels & biobased chemicals potentially disruptive? (1)

- Global energy demand is set to increase by 37% between 2013 and 2040 (IEA World Energy Outlook 2014)
- Security of supply is a growing issue
- Biofuels and biobased chemicals represent the only near-term alternatives to jet-, marine- and heavy-truck fuels as well as fossil based polymers
- Biofuels & biobased chemicals help to address global-warming concerns by reducing net greenhouse gas (GHG) emissions and non-renewable energy usage (NREU)
- Completely new value-chains have to be established

Why are biofuels & biobased chemicals potentially disruptive? (2)

- Greater use of (value from) wastes
  - improved circular economy, more efficient economy
- More local opportunities for production (more local jobs)
- More value added in the chain (improvements on resource extraction and export)
- Novel biobased (nano)materials
  - lightweight and new properties
- Both products and technologies can be disruptive
  - products: a.o. FDCA (PEF), succinic acid, lactic acid (PLA)
  - technologies: a.o. 2nd gen lignocellulose pretreatment, epichlorohydrin production, pyrolysis technologies

Potential impacts of biofuels and biobased chemicals

A. Geopolitical impacts

A large-scale move to energy-efficient biofuels and biobased chemicals could:

- Increase energy security
- Ease international competition for world oil supplies and reserves
- Satisfy international and national commitments to reduce greenhouse gas emissions
- Revitalize rural communities / circumvent urbanization

B. Military impacts

The development of a significant biofuels and bio-based chemicals economy could:

- reduce the likelihood of involvement in future military conflicts related to access to dwindling world-oil supplies
- lead to tailor-made and better performing fuels for the military

Potential Impacts of Biofuels and Bio-Based Chemicals

C. Economic impacts

- Global markets for biofuels are already growing rapidly in many countries. Global manufacturing and sales reached 1.5 million barrels / day in 2013 (IEA World Energy Outlook 2014)
- Biofuels can provide an economic hedge against higher oil prices as well as increase certainty of supply in the event of future oil-supply disruptions
- Reducing oil imports would help to improve the countries trade balance
- An oil-supply crisis would likely force a rapid transition to alternative energy sources, and if countries fail to develop a significant bio-based economy, they could fall behind other regions of the world economically
- Countries making a huge investment in biofuels might fail to address potentially cheaper solutions to reduce petroleum use

D. Cultural/Social cohesion impacts

- A successful transition could improve social cohesiveness and be a source of national pride if, for example, the impacts of global warming become serious
- A strong bio-based economy could also provide significant rural economic-development opportunities
- On the downside, if increasing demand for agricultural biomass to make biofuels can result in increased competition for natural resources

Potential Impacts of Biofuels and Bio-Based Chemicals

E. Industrial impacts

- Petrochemical refineries will become redundant or need major refurbishments to process biobased feedstocks
- New value chains have to be developed
- New liaisons between agricultural / forestry companies and chemical companies need to be established
- Incumbent processes can become under pressure / obsolete, e.g. epichlorohydrin from glycerol, biobased succinic acid
- More local production; more opportunities for smaller scales of production; multiple benefits
- Key element of a circular economy

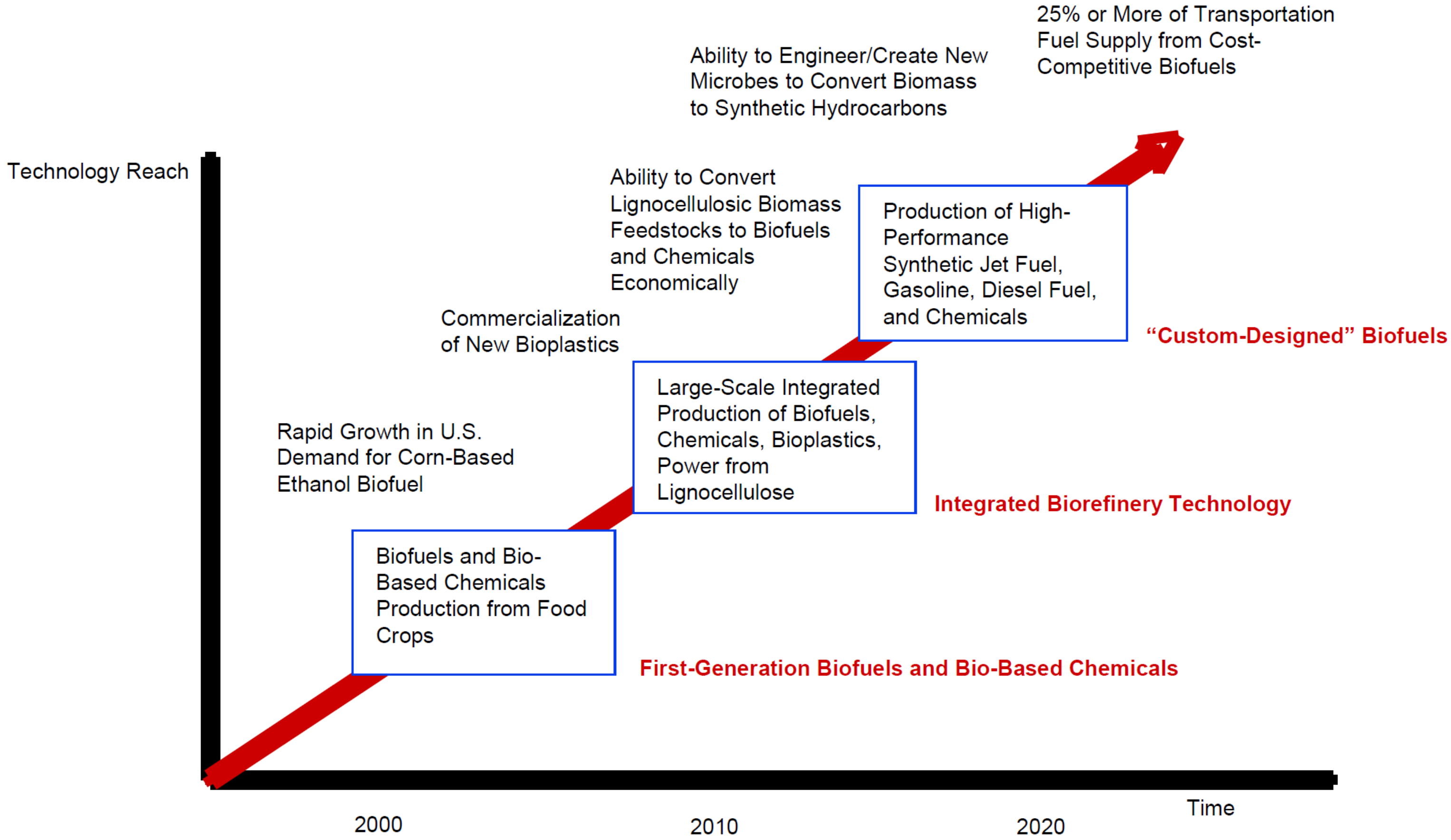
IEA Bioenergy

Task 42 Biorefineries

NIC study 2008

biofuels & biobased chemicals

TECHNOLOGY ROADMAP: BIOFUELS AND BIO-BASED CHEMICALS



Source: SRI Consulting Business Intelligence

Future scenarios and potential impacts

Key uncertainties that relate to biobased technology development and implementation are:

- Policy and funding & financing environment
  - the key uncertainty in the policy environment is the degree of commitment to promote a biofuels economy, which will be strongly influenced by the level of concern about issues such as energy security, global warming, food versus fuel discussions and crude-oil prices
  - the key uncertainty in the funding & financing environment is the availability of “abundant as well as cheap” capital in the form of equity, funds, loans and grants because this industry is very capital intensive
- Rate of technology advancement for enhanced capabilities and lower costs
  - the rate of technology advancement will be strongly influenced by the regulatory environment and the need to address feedstock constraints and reduce costs

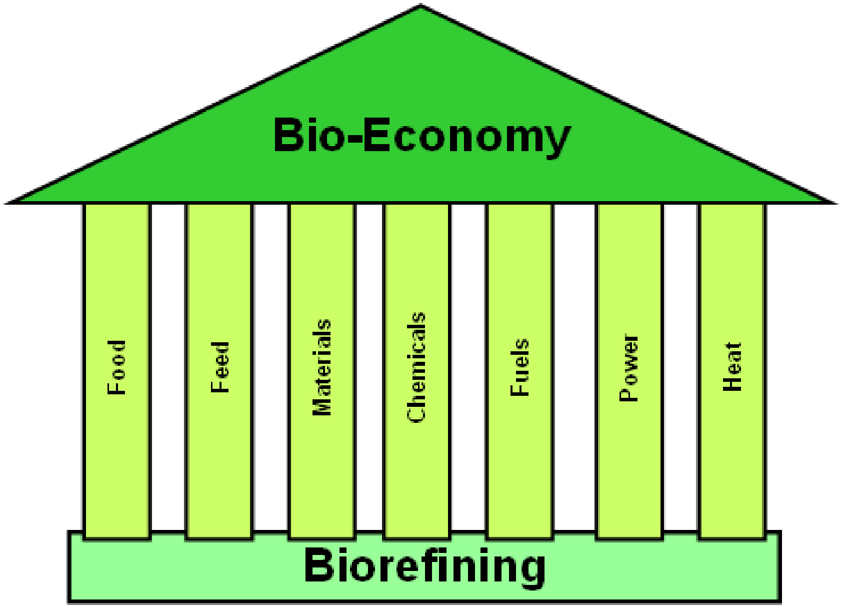
4. Biorefineries necessary to make Biofuels & Biobased Chemicals disruptive

Circular BioEconomy

A circular **BioEconomy** is based on:

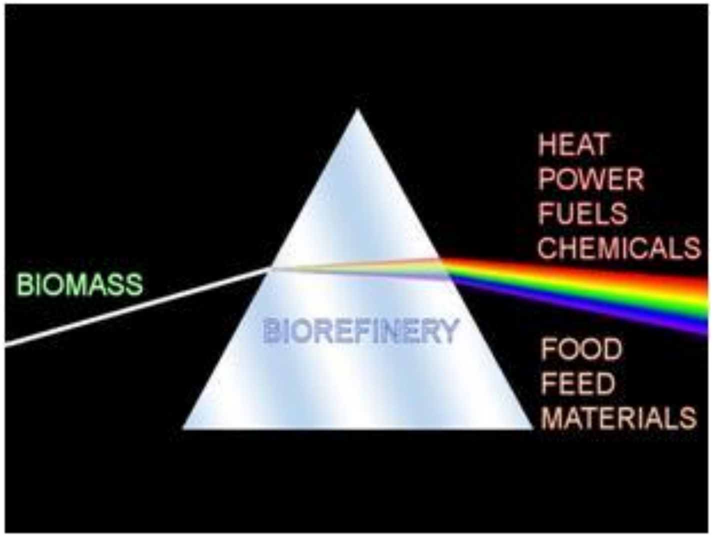
- Full sustainable value chains
- Relatively scarce raw materials availability
- Need for high-efficient zero waste conversion processes

Biorefinery approach is the main driver for large-scale biomass implementation in the future BioEconomy



Biorefining necessary to make B&B disruptive

Biorefining is the sustainable processing of biomass into a spectrum of marketable biobased products and bioenergy



Why is a biorefinery approach necessary to make biofuels & biobased chemicals (B&B) disruptive?

- to improve overall costing of the process
- to improve the sustainability of the process

Accenture disruptive (sub)technologies

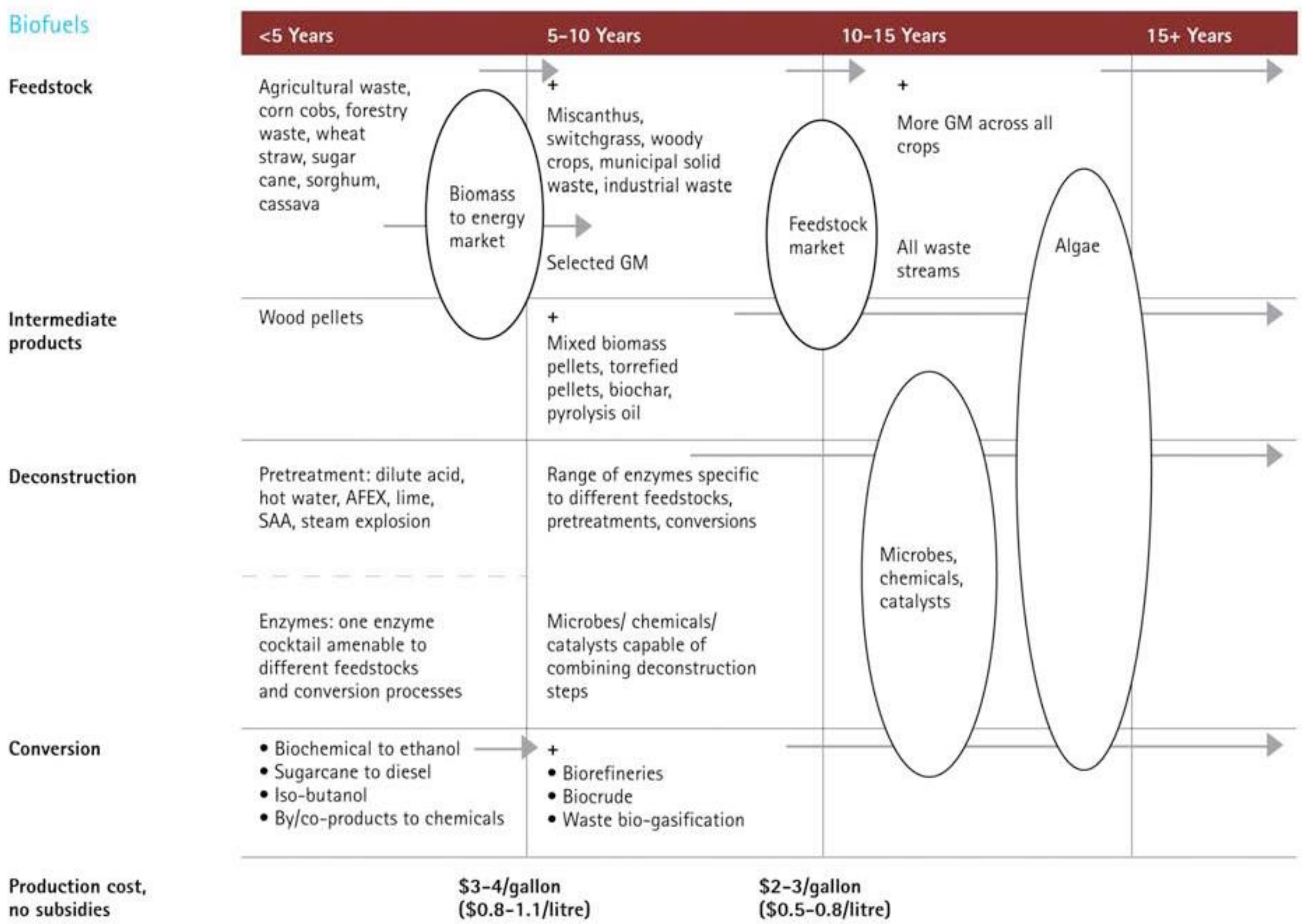
For a (sub)technology to be disruptive it needs to meet the following criteria (Stark et al. 2009; Stark & Jans 2010)

- **Scalable:** greater than 20 percent potential impact on hydrocarbon fuel demand by 2030
- **GHG impact:** savings greater than 30 percent relative to the hydrocarbon it is replacing
- **Cost**: competitive at an oil price of $45 to $90 per barrel, at commercial date
- **Time to market:** commercialization date in less than five years

IEA Bioenergy

Task 42 Biorefineries

Biofuels (Stark et al. 2009)



Aviation & Marine Fuels
(Stark et al. 2009)

IEA Bioenergy

Aviation

	<5 Years	5-10 Years	10-15 Years	15+ Years
Design improvements	Winglets retrofitted to existing aircraft Efforts at fleet renewal	Next generation of aircraft design		
Operational improvements	More efficient flight paths, ascents and descents	Improved air traffic control systems	Nascent use of biofuels in next-generation fleet	
Biofuel drop-ins	Continuation of trial flights using 50% biofuel drop-ins in one engine	First 100% bio-blend used in trial flight Wider deployment of bio-jet production facilities	Slow introduction at one or more hub airports	
Cost, no subsidies	**10% premium over crude price**	**10% premium over crude price**	**Higher premium due to feedstock supply constraints and conversion costs**	**Aviation biofuel processes more efficient but still a premium due to feedstock supply constraints**

Marine

	<5 Years	5-10 Years	10-15 Years	15+ Years
Scrubbers	Scrubbers commercially available. Limited take-up given size of investment, perceived complexity and low HSFO-LSFO differential	Lighter, smaller, more efficient scrubbers Some integration into ship design depending on customer fleet	Economically competitive scrubbers integrated into new-build ship design	
Port infrastructure for environmentally-friendly waste product disposal	Initial deployment	Wider deployment		
Operational improvements		Slower sailing speeds adopted to reduce emissions		
Design improvements	Some light weighting	Widely deployed light-weighting		
Business case	**Driven by time spent in ECAs and age of vessel and HSFO-LSFO cost differential**		**Driven by time spent in ECAs and age of vessel and HSFO-LSFO cost differential**	**Driven by global legislation and significant cost increase of LSFO**

Combined steps   Cumulative/ongoing

5. Disruptive (sub)technologies – Key Enabling Technologies

IEA Bioenergy

Task 42 Biorefineries

Disruptive (sub)technologies

Technology	Why	Status	Product	Companies	Challenge
Cellulosic fuels & chemicals	Food&Fuel debate, 2nd gen. feedstocks, Global presence	Commercial demonstration	Ethanol	DSM/Poet, Dupont, Granbio, Abengoa	Costs, scaling, logistics, heterogeneity, recalcitrance (cell wall)
Epicerol/GTE process for glycerin to epichlorohydrin	Economic & environmental considerations	Commercial	Epichlorohydrin	Solvay, Dow	Availability & costs glycerin
Synthetic Biology	Feedstock independent	Pilot plant, demonstration	Ethanol, algal biofuel, farnasene, isobutanol,	Algenol, Amyris, Gevo, Solazyme	Costs, scalability, technology
YXY process/ Catalytic carbohydrate conversion	Replacement of PET by PEF, superior technical properties, LCA benefits	Pilot Plant	Furan dicarboxylic acid	Avantium, ADM, Corbion	Costs, competition with bulk chemical PTA
Ethanol to MEG	Market pull (Coke, Heinze, ..)	Commercial	Mono-ehtyleneglycol	India Glycols, Greencol Taiwan	Drop-in molecule, only competes on price

IEA Bioenergy

Task 42 Biorefineries

Disruptive (sub)technologies

Technology	Why	Status	Product	Companies	Challenge
Genetic Engineering	Increasing yield, reduce costs, higher land use and resource efficiency; lower environmental footprint per tonne of product	Commercial	Crops, enzyme, microbes	Mendel, Ceres, Monsanto, Genencor, Novozymes, dyadic	GMO discussions (public acceptance) , ensuring safety, regulatory system,
Gasification Waste to Fuel/Chemicals	Relatively cheap feedstocks, landfill reduction	Demonstration	Fuels, methanol	Enerkem	Capital needed for investments
Pyrolysis	Feedstock agnostic, decentralised operations	Demonstration	Fuels	BTG	Quality of the fuel
Biocrude	Feedstock agnostic, quality of fuels	Demonstration	Fuels	Virent, Shell, Kior	Capital investments, scalability

Key enabling technologies

What are the key enabling technologies to make biorefining a disruptive technology?

- separation technology (both in pretreatment/work up)
- conversion technology
- small scale / de-centralised technology
- logistics and storage technology
- energy storage, energy from waste products, useful energy from waste heat

IEA Bioenergy

Task 42 Biorefineries

Disruptive technologies evolution

The development of a disruptive technology is always subject to great uncertainty. However we can pinpoint some reliable trends:

- Production costs will go down
- Feedstock will become cheaper (yield, processing, logistics, co-products value)
- The development will follow an S-shape curve
- First plants will be more expensive
- Incumbent technologies / products will be benchmark

Figure 10. Defining the short- and medium-term assumptions, plus further development potential.

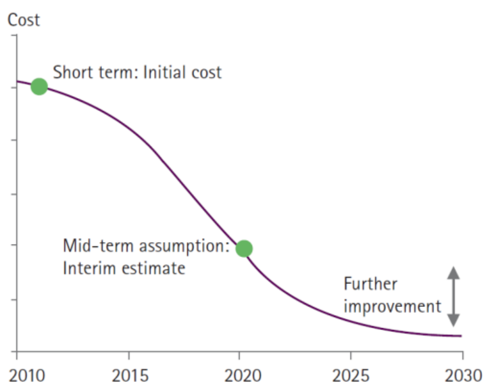
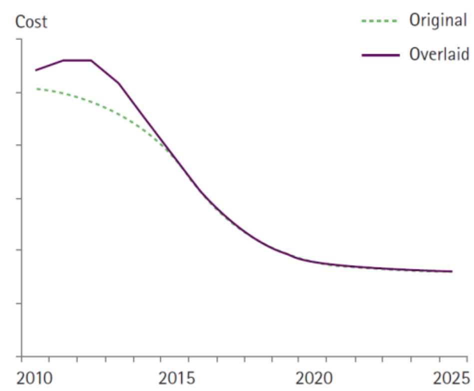


Figure 11. Overlaying higher-than-anticipated first commercial plant costs.



Indicators to Monitor (1)

Scenarios exist because of the uncertainty that is inherent with any view of the future

Determining which scenario best mirrors reality at any one time depends on careful assessment of reliable information and knowledge

There is a need monitoring various indicators that would indicate the direction and pace with which any field of uncertainty is advancing.

Key variables which, if positive, would indicate environments that are supportive toward biofuels and bio-based chemicals technology, include: (see next slides)

Indicators to Monitor (2)

- The timing and nature of biofuels promotion policies in the United States, Europe and other regions (e.g. quotas, subsidies, specific support for domestic or low-emission fuels)
- The world-wide timing and nature of global warming policies (e.g. carbon taxes, post-Kyoto Protocol carbon reduction agreements)
- The level of continuing R&D support from governments for the development and commercialization of advanced biofuels & biobased chemicals technologies
- Level playing field for biofuels & biobased chemicals
- Crude oil prices and supply
- Cost and efficiency improvements in biomass into biofuels and biobased chemicals conversion processes

Indicators to Monitor (3)

- The influence of food-versus fuel and indirect land use debates and public opinion on the availability of feedstocks such as corn, wheat and sugar beet and the spread of biofuels
- Improvements in feedstock yield and supply resulting from breeding and genetic modification of plants for very high growth or high products yields
- Scientists and engineers in leadership positions to guarantee breakthrough solutions as well as patent protection
- Partnering and business model flexibility to address all issues along the value chain and to complement in-house capabilities
- Availability and flexibility of capital
- Market specific strategy
- When multiple products are produced the markets for co-products much may be able to absorb higher production volumes

6. Conclusions

Conclusions (1)

- Biofuels & biobased chemicals can become a disruptive technology
- At present unclear which scenario becomes reality
- Valorisation of side-products at added value is critical to bring the costs down
- A biorefinery approach is therefore essential to bring this technology in the “fast lane”
- Availability of capital is limiting the growth of the field
- The amount and duration of cheap shale gas and shale oil impact on the biobased economy as well as preferred molecules is unclear

Conclusions (2)

- Biofuels and biobased chemicals are instrumental in the circular BioEconomy
  - only near term economic solution to make renewable carbon
  - allows for greater use of wastes and renewable feedstocks
- Several disruptive (sub)-technologies
  - genetic engineering
  - nanoparticles
  - chemicals from CO_2
  - brand new functionalities
  - cell wall disruption
  - energy from waste
  - energy storage

IEA Bioenergy

Task 42 Biorefineries

Literature

1. Bell, B.M., Briggs, J.R., Campbell, R.M., Chambers, S.M. et al. 2008. Glycerin as a renewable feedstock for epichlorohydrin production. The GTE process. Clean 2008, 36 (8), 657 – 661.
2. Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P. and Marrs, A. 2013. Disruptive technologies: Advances that will transform life, business, and the global economy. McKinsey Global Institute. http://www.mckinsey.com/insights/business_technology/disruptive_technologies
3. SRI Consulting Business Intelligence 2008. Disruptive Civil Technologies Six technologies with potential impacts on US interests Out to 2025. National Intelligence Council Conference Report CR 2008-07
4. Stark, M., Bellah, K., Cepera, H., Howorth, C. et al. 2009. Betting on Science - Disruptive Technologies in Transport Fuels. http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture_Betting_on_science.pdf
5. Stark, M. and Jans, C. 2010. Real-time S-curves Valuing technology uncertainty in disruptive transport fuel technologies. http://www.accenture.com/sitecollectiondocuments/pdf/accenture_real_time_s_curves.pdf
6. IEA World Energy Outlook 2014. http://www.iea.org/textbase/npsum/weo2014sum.pdf

IEA Bioenergy

Task 42 Biorefineries

Contact Information

Ed de Jong
(ed.dejong@avantium.com)

www.IEA-Bioenergy.Task42-Biorefineries.com

Acknowledgements

All active partners of IEA BioEnergy Task 42 on Biorefineries are sincerely thanked for fruitful discussions, helpful suggestions as well as critical remarks.

Annex 1

Scenarios NIC study

IEA Bioenergy

Task 42 Biorefineries

NIC Study 2008

Biofuels & biobased chemicals

4 Future Scenario's

BIOFUELS AND BIO-BASED CHEMICALS: FUTURE SCENARIOS

		Rate of Technology Advancement	
		Incremental	Rapid
Policy and Funding	Lack of Support	**Stalled**	Economic Biofuels
	Strong Commitment	Supported Growth	**Biofuels in the Fast Lane**

Source: SRI Consulting Business Intelligence.

NIC Study 2008 & beyond

BioFuels & Biobased Chemicals

4 Scenario's:

- Most issues and uncertainties of 2008 report are still out there
- Study updated till 2015
- New issues not mentioned before
  - Capital availability for scale-up
  - Shale-gas revolution
  - Global recession of 2008
  - Strong drop in the oil prices

The four Scenario’s:

- Stalled
- Supported Growth
- Economic Biofuels & Biobased Chemicals
- Biofuels & Biobased Chemicals in the fast lane

Stalled (1)

- A vibrant biofuels economy does not materialize.
- Governments decide that large biofuels subsidies are not the best use of public monies and begin to scale back ambitious biofuels targets.
- Investment tax credits for blending biofuels into gasoline and diesel at low concentrations remain in place, supported by vociferous corn- and soy grower lobbies
- Crude-oil prices remain relatively high—in the $50-to-$75-per barrel range—but environmentally conscious consumers prefer to purchase high fuel-efficiency hybrid and electric vehicles rather than flex-fuel vehicles—especially because the availability of E- 85 fueling stations remains quite limited.

Stalled (2)

- Although governments worldwide (including the US government) agree to take real action to reduce greenhouse gas emissions, the use of biofuels is not a preferred path.
- Despite significant public and private R&D funding through the early 2010s, second-generation technologies do not advance sufficiently to make cellulosic ethanol and other new biofuels and bio-based chemicals close to being cost competitive with petroleum-based counterparts.
- Reliance on crop-based biofuels has led to sustained higher prices for a range of food products, resulting in a backlash against biofuels by the general public.
- By 2025, biofuels represent just 5% of the US transportation fuel pool

Stalled (3)

(Opportunities & Treats)

Potential opportunities.

- Governments could continue R&D to improve biomass feedstocks and biofuels with no need to take on the risk of rushing new technologies into production before they are viable.
- A more market-based approach to energy issues could be developed
- Alternative actions to address global warming could be taken focusing on those applications (jet-marine & heavy duty fuels, chemicals) were no alternatives are available.

Potential threats

- There is less room to maneuver to address periodic crude-oil–supply disruptions and future upward trends in oil prices, as supplies of nonconventional energy supplies eventually decline
- The world would remain dependent upon several less-than-friendly oil-producing countries for key energy supplies

Supported Growth

- Advances in biofuels technology have been slow
- Most production still relies on 1st generation (food crops) for feedstock
- Some biofuels markets have seen significant growth
- Governments have continued to mandate the use and provide subsidies to help make biofuels cost-competitive with conventional fossil fuels
- A number of industrialized and developing countries that have the economic and/or land resources to make a major dent in dependence on imported crude oil have been willing to make a large public commitment to biofuels.

Economic Biofuels & Biobased Chemicals

- Private sector is the main driver of a steadily growing biobased economy sector
- Technology breakthroughs have led to the manufacture of large-scale second- and third-generation biofuels & biobased chemicals that are increasingly cost-competitive.
- Many governments nurtured the early growth but gradually cut biofuels subsidies as markets became selfsustaining
- The largest biofuels markets emerge in areas with ready access to biomass resources from wastes and energy crops optimized for biofuels production.

Chemicals in the fast lane (1)

- The world confronts an increasingly energy-constrained world that requires new, cleaner, safer, and more secure energy solutions
- As conventional crude oil production declines related to demands, prices are steadily above $100/barrel
- Physical impacts of global warming - especially more severe weather patterns and collapsing fish populations - demand drastic steps to reduce GHG emissions
- Supported by public opinion, the governments commits to a “Brazil model” of widespread biofuel use

Chemicals in the fast lane (2)

- Governments help to fund new commercial-scale plants and a flexible fuel infrastructure
- Biorefineries processing lignocellulosic & waste feedstocks are becoming common throughout the world
- Technology breakthroughs have significantly lowered the cost of converting agricultural wastes
- Cellulosic ethanol is now very cost competitive with high-priced conventional gasoline
- Ethanol-fueled hybrid vehicles are in great demand
- Newer synthetic “designer fuels” offer even higher performance and are in wide use in jet-fuel blends
- Commodity and specialty chemicals and bioplastics also increasingly are derived from renewable feedstocks, and producers benefit from more energy efficient manufacturing and environmentally friendlier products

Chemicals in the fast lane (3)

Potential opportunities

- Established economies have the opportunity to take the lead in developing low-net-carbon advanced biotechnologies and other processes to produce 2nd- and 3rd-generation biofuels and bio-based chemicals
- In spite of oil price shocks and tight supplies, the economies could benefit from increasing oil independence and increasing entrepreneurial activity, especially in rural areas
- The G8 countries could also gain political influence by working cooperatively with BRIC countries such as China and India that are also making a major transition away from fossil-based fuels
- New synthetic fuels with improved performance could be useful for especially the aviation industry and the military
- Biobased chemicals with novel functionalities such as lactic, succinnic and furandicarboxylic acid reinvents the chemical industry

IEA Bioenergy

Biofuels & Biobased Chemicals in the fast lane (4)

Potential threats

- Economies may not be able to move fast enough to enable a major Biofuels & Biobased Chemicals economy fully by 2025
- The economic recession continue to cause a severe economic recession and cash-strapped governments and citizens may not be able to afford the new plant capacity, infrastructure upgrades, and vehicles necessary to the transition
- With a continuing abundant shale gas supply, especially the US government may lose citizens and industry support