GREATER THAN THE SUM OF ITS PARTS

HOW BIOFUELNET HELPED POWER UP THE BIOENERGY SECTOR

2012-2017

RÉSEAU BIOFUELNET CANADA

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RÉSEAU BIOFUELNET CANADA

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Networks of Centres of Excellence of Canada | Réseaux de centres d'excellence du Canada
2012-2017

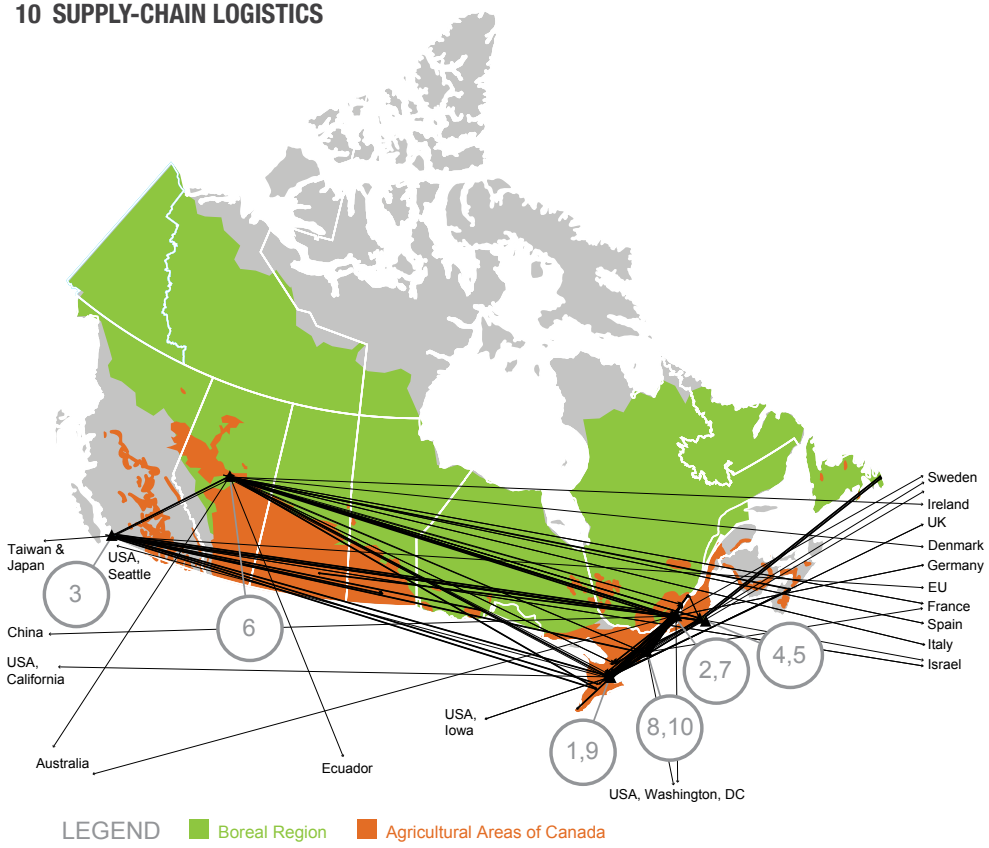
EXECUTIVE SUMMARY

BioFuelNet Canada (BFN) grew out of a need to tie the disparate threads of the Canadian biofuels research, development, and business communities together. From 2012 to 2017, with support from the federal government through the Networks of Centres of Excellence (NCE) program, BFN operated as the only national organization that integrated academic researchers, industry partners, investors and government representatives in collaborative initiatives in this field. By creating goal-driven research teams, forging deep communication grooves across the country, and prioritizing R&D projects with the greatest potential to affect Canadian biofuels development, BFN paved the way for an enduring Canadian bioeconomy.

BFN's story highlights how NCEs can jump-start Canadian innovation and development, to the ultimate benefit of Canadian society. This network final report celebrates BFN's achievements and considers the key role of a national network in the development of a robust biofuels sector.

BIOFUELNET NETWORKING **PROJECTS**

1 PURPOSE-GROWN FEEDSTOCK
2 RESIDUES & WASTES
3 BIOCONVERSION
4 PYROLYSIS
5 GASIFICATION
6 EMERGING CONVERSION TECHNOLOGIES
7 COMBUSTION & ENGINE OPERATIONS
8 LIFE CYCLE ANALYSIS & MICROECONOMICS
9 DOMESTIC & INTERNATIONAL POLICY
10 SUPPLY-CHAIN LOGISTICS



IMPACT BY THE NUMBERS

$25 MILLION
NCE

$21 MILLION
INVESTED BY STAKEHOLDERS

713
HQPS TRAINED

230
RESEARCHERS ENGAGED

29
UNIVERSITY PARTNERS

127
INDUSTRY PARTNERS

38
PRODUCTS AND INNOVATIONS

22
LICENSING AGREEMENTS

5
POLICY BRIEFS

5
SPIN-OFF COMPANIES

970+
PUBLICATIONS

4,500+
CITATIONS

108,000
WEBSITE VISITS IN 2016

6,550
VIEWS OF 24 YOUTUBE PRESENTATIONS

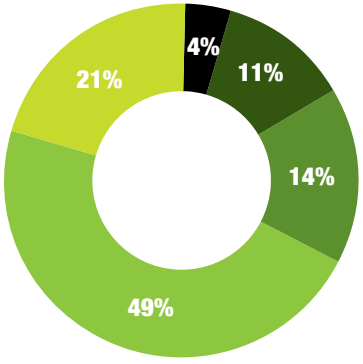
3,500+
SOCIAL MEDIA FOLLOWERS

RESEARCH & DEVELOPMENT

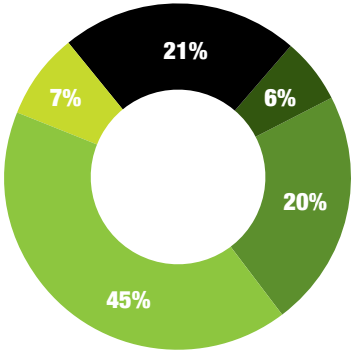
BFN provided the networking power and financial support to enable researchers across disciplines to meet, collaborate and make high-impact advances in biofuels technology. At the same time, BFN continually sought—and found—opportunities to bring academia and industry together to help move the research through the development cycle. Some examples:

- By growing willow trees at a 45-degree tilt, BFN researchers under the supervision of Université de Montréal adjunct professor Michel Labrecque discovered the biology behind the cellulose-rich "tension wood" that underpins biofuel yield. The scientists also identified willow varieties and growth techniques that increased the trees' capacity to clean up polluted soil, as well as the biochemistry behind this high tolerance capacity which they also exploited for substantially increased green chemicals production (bioproducts). The prospect of a "super-crop" with multiple value streams drew interest from several partners, who collectively infused cash and in-kind contributions of $153,000 into the project.
- Led by University of British Columbia engineering professor Dr. Shahab Sokhansanj, recipient of the 2016 Founders' Award in Bioenergy Excellence, BFN researchers developed a novel, energy-efficient process for steam-treating wood pellets. The process yields unusually strong and durable pellets tailor-made for conversion into usable bioproducts such as biochar and biocoal. Global Bio-Energy Inc. is working with this BFN research team to commercialize the breakthrough process.
- Patent pending: A BFN research team working under the director of the Clean Combustion Engine Laboratory at the University of Windsor, Dr. Ming Zheng, developed a system that improves the ignition rate of spark-ignition engines (such as car engines) burning biofuels by up to 50%, while using only half the energy of a conventional spark plug. Other BFN scientists created a similar boost for diesel engines. The Ford Motor Company of Canada is interested.

BFN Partners at a glance

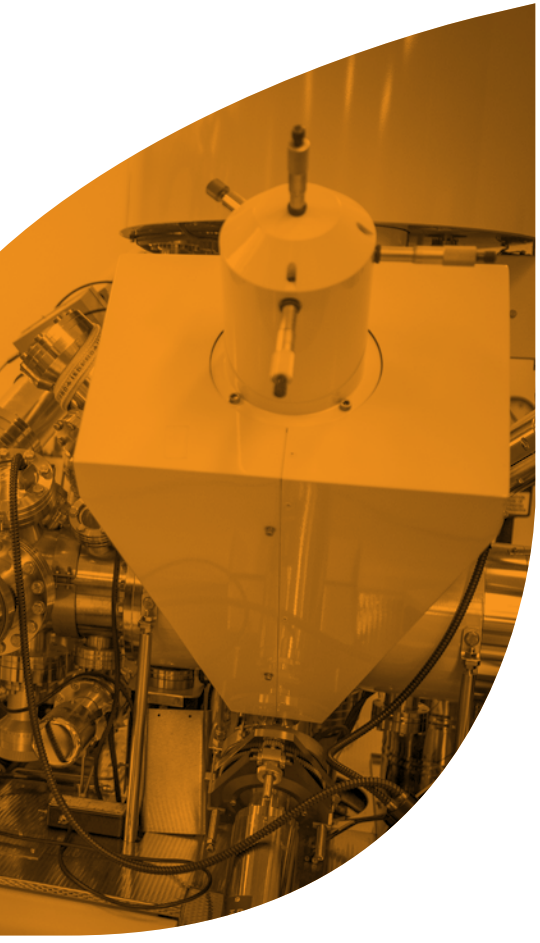


Network Partners Segments
2012-2017 (260 Partners)



Network Partners Contribution
2012-2017 (Non-NCE: $21M)

Academic Institutions
Federal Agencies
Provincial Agencies
Industry Partners
Other



KNOWLEDGE TRANSLATION

BFN adopted a four-pronged strategy to push new technologies and supply-chain models into the real world. The strategy gave birth to initiatives such as:

- A technology called FlueTRU© helps purify emissions from industrial biomass boilers, producing high-quality carbon dioxide that can increase yields and profits in greenhouse operations while protecting the climate. Seeing a win-win opportunity, BFN helped develop a business case for the technology, built a prototype, and tested it in an operational greenhouse.

- With Air Canada as a major partner, BFN co-launched an initiative to boost the proportion of biojet fuel used in air transport. Industrial partners committed a total of $1.2 million to the project, on top of BFN's $186,000 contribution. As a test run, about 400,000 litres of biojet fuel will be funnelled into the fuel delivery system at Montreal's Pierre Elliott Trudeau International Airport.

- BFN sustainability researchers identified an urgent need to develop specialized biofuel substitutes to meet Canada's greenhouse gas (GHG) emissions challenge. Enter Forge Hydrocarbons, a new company launched through BFN's connections and support. With a focus on converting lipids to hydrocarbon biofuels, the company raised $5 million in seed money—and then enough to develop a commercial plant announced in March 2017.

SPIN-OFF COMPANIES

TECH MACVERT
(Lefsrud, Project 2)

ALGOMEGA
(Barnabé, Project 6)

FORGE HYDROCARBONS
(Bressler, Project 3)

CLEAN COMBUSTION ENGINE TECHNOLOGY INC.
(Zheng, Project 7)

BIO-TECHFAR
(Berruti, Project 4)

COMMUNICATION

Knowing that a healthy bioeconomy depends on the free flow of information, BFN used several strategies to keep stakeholders informed and engaged, including:

- Disseminating information about biofuels through multiple media channels, making BFN a leader in media presence among NCEs
- Writing articles about BFN researchers' most impactful work
- Organizing the Advanced Biofuels Symposium, which became the largest conference in Canada on Advanced Biofuels
- Writing policy briefs to inform government and industry leaders about key biofuels issues and applications
- Raising the profile of the sector through 48 media pickups, 20 of which were in mainstream media

EDUCATION AND HQP TRAINING

BFN identified Canada's most promising young biofuels researchers, collectively designated as Highly Qualified Personnel (HQP), and supported these individuals along their path to professional maturity. To ensure the HQP "tree" grew strong and straight, the Network:

- Gave HQP a steady stream of opportunities to engage in collaborative R&D, balancing training opportunities across several disciplines
- Gave HQP industry experience to help them learn the business of biofuels
- Devoted one day of each annual Advanced Biofuels Symposium (ABS) to HQP training, with a strong focus on entrepreneurial skills
- Developed an online Advanced Biofuels Course (ABC) and 24 educational videos and webinars on BFN's YouTube channel

A SURVEY OF BFN GRADUATES (2012-2015) SHOWED THAT

Almost half secured jobs or continued their education in academia within Canada;

30% are employed in industry (29% in industry within Canada);

11% entered academia outside of Canada and

only 5% were looking for work.

NUMBER OF HQP TRAINED BY THE NETWORK (NON-CUMULATIVE)

	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017
Undergraduate	21	47	60	46	68
Master's	52	83	99	71	95
PhD	64	82	98	80	97
Post-Doctoral	21	35	37	60	63
Technicians / Research Associates	11	30	34	27	49
Total	**169**	**277**	**328**	**284**	**372**

LOOKING AHEAD

BFN has permanently changed the way Canada's university research community and industry partners work in biofuels and the Network's strong performance in training HQP has prepared the next generation of industry leaders.

Some of the bottlenecks to the development of the bioeconomy that have been identified by BFN remain. More work needs to be done at various levels, but thanks to the NCE's investment and BFN's networking impact, the wheels of innovation and collaboration it set in motion continue to roll. **As a lasting legacy for Canada, BFN's work goes on to maintain the momentum of the NCE's investment for years to come.**

GREATER THAN THE SUM OF ITS PARTS

NETWORK FINAL REPORT

THE WHY

Things have got to change. For the past several decades, scientists and policymakers have been looking for ways to decarbonize the Canadian energy sector. Concerned about greenhouse gas (GHG) emissions from fossil fuels and the impact of climate change, experts have been looking far and wide for alternatives.

The first decade of the millennium saw a surge of interest in biofuels. In a country with abundant biomass resources, such as agricultural and forestry by-products, biofuels made sense.

Across the country, researchers began working on more efficient and economical ways to extract biofuels from biomass. In the absence of a centralizing force, however, the sector progressed in fits and starts. Lacking communication channels, university labs often worked in isolation. Lacking the means to scale up their discoveries, R&D departments and start-up companies often left their best ideas on the drafting table.

Recognizing the potential locked in Canada's biomass, a group of researchers approached the federal government to fund a network devoted to spurring the production of advanced biofuels and creating a vibrant Canadian bioeconomy. Since its 2012 launch as a Network of Centres of Excellence (NCE), BFN has used these statements to guide its actions:

- **BFN Vision:** the emergence of a socially, economically and environmentally sustainable and globally competitive Canadian bioeconomy, based on advanced biofuels and associated bioproducts
- **BFN Mission:** to catalyze the expansion of Canada's bioeconomy by creating a national network to drive the commercialization of advanced biofuels and associated bioproducts through integrated research, innovation, smart policy and strategic partnerships

THINGS HAVE BEGUN TO CHANGE.

Throughout its 5-year mandate, BFN took the message to heart and helped set Canada on a cleaner, more diverse, and more sustainable energy course. Here is how it happened.

FAST FACTS

BFN attracted 260 partners who collectively provided $21 million in support for its mission

THE APPROACH

To realize its vision of a thriving bioeconomy, BFN prioritized activities that integrated biofuel production within the existing energy infrastructure, rather than developing a segregated track for biofuels. To this end, the Network supported and linked various biofuels labs and interested partners to enable knowledge-sharing and scale-up of emerging technologies.

THE STRUCTURE

BFN was hosted by McGill University. A board of directors, consisting of senior representatives from various organizations including advanced biofuels companies, provided high level oversight to the Network. The governance structure also included eight committees with experts from academia, industry and government. Full-time staff included a scientific director, an executive director, and a government liaison officer, supported by a lean administrative staff that handled operations.

FAST FACTS

BFN used only 13.4% of its budget for administrative expenses, comfortably below the 15% cap set by the NCE

HOW BFN GREW UP

BFN activities fell into two phases: Phase 1, from launch to early 2015, and Phase 2, which carried the Network to the end of its mandate.

Phase 1 snapshot

In Phase 1, BFN established its governance structure, laid the groundwork for a community of investigators and partner organizations, and selected four themes to anchor its R&D priorities: feedstock, conversion, utilization, and SEES (Social, Economic and Environmental Sustainability). To ensure a fair balance of funding support across Canada, BFN integrated these themes with four regions of the country: West, Prairie, Central, and East.

In early 2014, BFN launched an online member portal that served as a “Grand Central” hub for the Network. The tool allowed scientists, committee chairs and members of the administrative team to connect quickly and easily with each other, to exchange and report on data.

Phase 2 snapshot

By the end of Phase 1, BFN understood which projects had the greatest potential to move the Canadian biofuel industry forward, and made such projects a priority in Phase 2. In brief, BFN funded *fewer* and *more integrated* projects during this phase.

BFN created a structure of 10 integrated projects, each containing multiple work packages within a core research theme. Six task forces were mandated to commercialize the results coming from multidisciplinary research. This structure enabled high-impact collaborations that would have been impossible without a central organizing force.

10 PROJECTS

1 PURPOSE-GROWN FEEDSTOCK
2 RESIDUES & WASTES
3 BIOCONVERSION
4 PYROLYSIS
5 GASIFICATION
6 EMERGING CONVERSION TECHNOLOGIES
7 COMBUSTION & ENGINE OPERATIONS
8 LIFE CYCLE ANALYSIS & MICROECONOMICS
9 DOMESTIC & INTERNATIONAL POLICY
10 SUPPLY-CHAIN LOGISTICS

6 TASK FORCES

INTEGRATED
BIOLOGICAL BIOREFINERY
BIOFUELNET

POLICY
BIOFUELNET

FORESTRY
BIOFUELNET

INTEGRATED
THERMAL BIOREFINERY
BIOFUELNET

LOW COST
SUSTAINABLE FEEDSTOCKS
BIOFUELNET

AVIATION
BIOFUELNET

THE THEMES THAT DROVE DISCOVERY

The four themes that underpinned BFN's research initiatives reflect both the sequence and the challenges of biofuel development: the raw material or feedstock (theme 1) must be converted (theme 2) into a biofuel end-product that is both usable (theme 3) and sustainable (theme 4).

BREAKTHROUGH

A plant growing under field conditions is a community; it always has a large population of associated microbes. The plant and these microbes have evolved together; the microbes allow the plants to better deal with various environmental challenges. McGill University professor Donald Smith's group has been involved in research that disclosed a new activity for the microbe-to-plant signals that cause a general stimulation of growth for most plant species, and particularly under stress conditions. This has now been commercialized and is applied each year to ~100 million hectares of agricultural land worldwide. During the period of BFN funding, as part of BFN's feedstock theme, the Smith lab demonstrated that the signal compounds dramatically improve plant stress tolerance, making them more able to grow on marginal lands (generally more stressful) and under the more stressful conditions that will be more common as climate change conditions continue to develop. This work has also shown applicability to purpose grown biofuel feedstock crops, all leading to enhanced production of advanced biofuels.

FEEDSTOCK THEME

It all starts with feedstock. Feedstock availability represents the ultimate constraint in producing biofuels sustainably. What are the most abundant and energy-efficient sources of biomass from which to create biofuels? Forests are an obvious option, but which trees? Crops such as corn also have potential, but food crops must be used with caution. And what about the rich plant life that exists underwater?

BFN funded several research projects that helped identify the best sources of biomass in Canada, with an emphasis on harnessing the power of forest and agricultural biomass that currently goes to waste. Also under the feedstock umbrella were projects that studied the genetics of woody species and grasses, low-input growth methods, and efficient methods for harvesting purpose-grown energy crops.

BREAKTHROUGH

As environmentally-friendly and cost-effective sources of bioenergy, wood pellets are finding increasing commercial uses. Led by University of British Columbia engineering professor Dr. Shahab Sokhansanj, recipient of the 2016 Founders' Award in Bioenergy Excellence, BFN researchers developed a novel steam-treating process that yielded denser, more crumble-resistant pellets. (Crumbled pellets can create noxious dust and also present an explosion hazard.) BFN partner Global Bio-Coal Energy Inc. works with the BFN research team to commercialize the process.

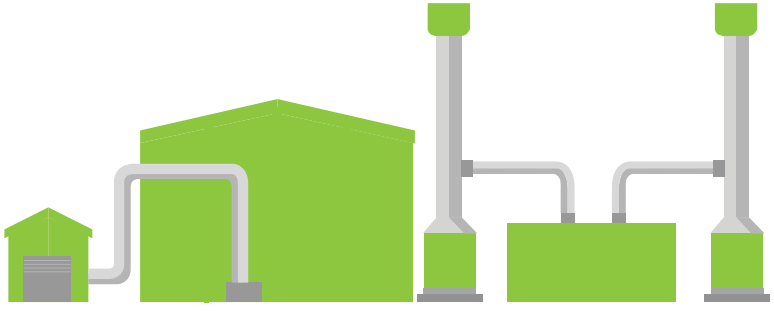
CONVERSION THEME

Converting raw material into biofuels takes energy—and money. Without efficient and cost-effective conversion technology, the best feedstock will sit unused.

The conversion theme explored several avenues to boosting efficiencies. Biochemical projects looked into developing cheaper and faster enzymes to convert cellulose and hemicellulose into alcohol-based fuels. Thermochemical projects tweaked the pyrolysis and gasification steps in the production of "drop-in fuels" such as gasoline, diesel fuel or jet fuel. Other projects focused on integrating conversion processes into "full-service" biorefineries.

BREAKTHROUGH

Methane reforming is the process of producing pure hydrogen from methane gas. Dr. Nicolas Abatzoglou, a chemical and biotechnological engineering professor at the Université de Sherbrooke, and his research team developed a method to dramatically increase the efficiency of methane reforming. The method uses 50% less water than the baseline, which translates to a 30% decrease in energy requirements. The new-and-improved technology also works for reforming tail gas (exhaust gases from natural gas processing). The "new and improved" process has given a substantial boost to the commercial viability of methane reforming.



UTILIZATION THEME

A biomass source may be plentiful, a conversion process may be elegant, but if the end-product does not have practical uses, the innovation will not go forward. Factors that can compromise usability include contaminants, weak energy yield, and (in the case of drop-in fuels) poor compatibility with automotive and aircraft engines.

BFN's utilization theme supported the development of biofuels that make both technological and business sense—products that perform. To this end, BFN examined various uses of biofuel products, prioritized conversion projects that led to "ready-to-use" biofuels, and brought developers and end-users together.

BREAKTHROUGH

Biofuels can run into several glitches when they are injected into engines. Ignition can sputter, combustion can drag, exhaust fumes can proliferate, and biofuel components can weaken moving parts and seals. As director of the Clean Combustion Engine Laboratory at the University of Windsor, Dr. Ming Zheng had just the right credentials to tackle these challenges. He and his research team developed an in-cylinder emission control system to reduce soot and NO_x pollutants and a high-efficiency igniter for spark-ignition engines. The igniter boosted the ignition success rate by 50%, while requiring only half the energy of a conventional spark plug. Along similar lines, BFN researchers developed a spark-assisted ignition system to help biofuel-powered diesel engines ignite more efficiently. These technologies will make biofuels significantly more practical to use in car engines.

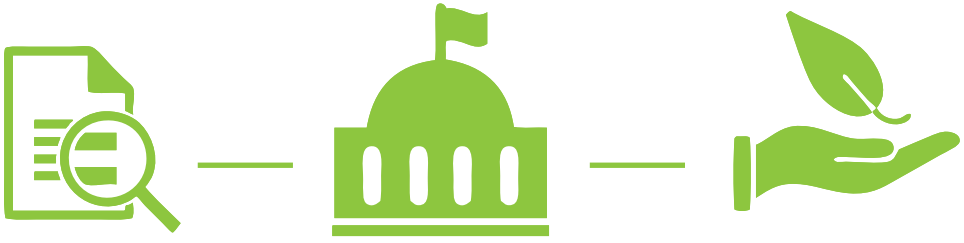
SEES THEME

Sustainable does not just mean environmentally friendly. It also means socially sensitive and financially responsible. It requires a wide-angle view of R&D, one that considers all aspects of the value chain.

This is why BFN chose SEES [Social, Economic and Environmental Sustainability] as one of its core themes. Researchers working within this theme performed impact assessments that considered the economic, social, and environmental aspects of a technology, and life-cycle assessments that put numbers on energy consumption and emissions from various processes. Projects that assessed existing policies and made recommendations to government and industry also fell under the SEES umbrella.

BREAKTHROUGH

How do biofuels stack up against petroleum-based systems? To address this all-important question, Dr. Joann Whalen, a McGill University professor and president of the Canadian Society of Soil Science, quantified the potential impact of biofuels on GHG emissions in specific sectors, such as ground transportation and aviation. She and her collaborators also put hard numbers on the bioeconomy's potential to meet climate change challenges. This work informed the BFN Policy Task Force's recommendations on issues ranging from low-carbon fuel pricing to carbon pricing. Governments are listening.



BFN IMPACT: A LEGACY OF MORE

Picture a group of researchers sitting at a long harvest table, discussing their respective projects while sharing a traditional Canadian meal in Old Montreal. One of them, still a student, mentions her dream of extracting biofuel from marine life. As it happens, another researcher at the table has been evaluating different types of micro-algae as feedstock sources. The discussion piques the interest of a third member of the party, who owns a waste-to-biofuels facility and has been looking to invest in novel energy sources. The three parties have agreed to talk again at a later date.

At BFN conferences and other networking events, such scenarios unfolded routinely. By bringing stakeholders from all corners of the biofuel landscape together, BFN provided the spark that turned dreams into ideas, ideas into research projects, and research projects into commercial ventures.

When we talk about the whole being "greater than the sum of its parts," we often mean that a group has more impact than the individuals comprising it. By connecting and supporting individuals across the biofuels space, BFN exemplified this principle.

MORE PURPOSE-DRIVEN RESEARCH: IDEAS WITH LEGS

Ideas for ideas' sake. It is an attractive concept, but when it comes to energy, Canada does not have the luxury of pursuing ideas that eventually wither on the vine. That is why BFN's research program prioritized projects that might one day end up as better fuels, better plastics, or other products made in a biorefinery using novel feedstocks. By bringing researchers across disciplines together and supporting projects that broke new ground, BFN served as a "great accelerator" of research and innovation.

FAST FACTS

All told, BFN generated 976 publications, 38 patents, 22 licencing agreements, 7 business cases and 121 KT activities

SHOWCASE: THE BIG TILT

Once in a while, a scientific discovery seems so far-fetched or just plain weird that it catches everyone by surprise, not least the person who came up with it. Such was the case with Nicholas Brereton, who determined that growing willow trees at a sharp angle increased their biofuel yield by significant amounts.

A research fellow at the Université de Montréal's Institut de Recherche en Biologie Végétale and graduate of Imperial College London in the U.K., Dr. Brereton had tested several other growth conditions in hopes of squeezing extra "juice" from the willow trees, but none had panned out. **"Tipping trees seemed a little ridiculous, but testing fanciful ideas is part of the scientific process,"** he says. BFN's research-funding committee agreed.

On trips to Scotland, Dr. Brereton had observed that strong winds put considerable pressure on willow trees, tilting their trunks at angles up to 45 degrees. When he analyzed the wood from those trees, he discovered that it produced five times more sugar than expected. **"The difference was bigger than anything we'd ever tested before,"** he says. **"It blew our minds."**

Intrigued, Dr. Brereton set about replicating the tilted growth pattern in more controlled conditions, under the supervision of Université de Montréal adjunct professor Michel Labrecque. It worked: the wood in these "cultured" willows showed the same qualities as the wood in the windswept Scotland trees.

Dr. Brereton wanted to know why. Computer tomography (CT) equipment, which enabled him to view the wood at a cellular level in three dimensions, gave him the answer. **"We found that tilting the tree prolongs the life of certain cells that would normally die,"** he says. This leads the tree to produce a gelatinous, sugar-rich fibre—the tree's strategy for staying upright—that accounts for its increased biofuel yield.

Willow trees have a lot going for them—especially in Canada, where they comprise about a third of the woody flora. They absorb nutrients efficiently, grow very fast, and **"some varieties have the highest-recorded biofuel yield of any trees on the planet,"** says Dr. Brereton. They also **"survive in windy slopes and poor soil where more delicate species might not make it."**

Willow trees have yet another stand-out feature: they can help decontaminate polluted soil. If the factors that increase the trees' biofuel yield and clean-up power overlap, **"the commercial applications could be huge."**

WASTE NOT, WANT NOT

As head of BFN's Residues and Waste team, McGill University associate professor Mark Lefsrud devoted his attention to untapped bioresources. His team's research on low-quality degraded trees demonstrated that using these "unloved woods" as feedstock could make biofuel production far more profitable. Team members also developed a technology (FlueTRU©) to remove impurities from flue gas, thus enabling the gas to provide carbon dioxide for greenhouses. Two patents and a spin-off company have brought their vision down to earth.

MORE APPLICATIONS: PUSHING IDEAS INTO THE REAL WORLD

When it came to translating ideas into products and processes, BFN did not leave researchers to their own devices. BFN's task forces sourced out industrial partners with the will, the means, and the infrastructure to develop the ideas. BFN also provided support to researchers seeking to launch start-ups, file patent applications, and negotiate with governments.

LOVING UNLOVED WOODS

Université Laval adjunct professor Évelyne Thiffault and her industrial and community partners have spearheaded an effort to extract value from unloved or otherwise underutilized woods as a feedstock for biofuels. The insights obtained caught the attention of the Government of Québec as basis for new policies to mobilize forest bioenergy in Québec.

FAST FACTS

BFN created a searchable database of over 489 companies in the Canadian biofuels space and brokered 93 business-to-business introductions, of which many led to commercial partnership agreements.
$4.1 B invested in Canada alone during 2012-2017

SHOWCASE: THE SKY IS GREEN

Air Canada wanted to know if there was enough biomass to supply their needs in biojet fuel. BFN researchers concluded that Canada's natural resources could be tapped to produce sufficient amounts of alternative fuels for aviation. Still, even if a suitable biojet fuel is produced, how to get it from the biorefining plant to the plane remains a challenge.

When an airline buys fuel from a supplier, a carefully orchestrated infrastructure moves the fuel from a "tank farm" through an underground grid and finally to a pump truck that transfers the fuel into the plane. BFN, collaborating with Canada's Biojet Supply Chain Initiative (CBSCI), saw an opportunity to inject more biojet fuel into the system.

Historically, **"most biojet has been delivered to the airplane wings by fuel bowser trucks,"** says Fred Ghatala, a partner in the Waterfall Group strategic consultancy and manager of the CBSCI project. **"That's like carrying around batteries to every room of your house rather than having power outlets you can plug into."**

To bring costs down to competitive levels, biojet fuel needs to enter the system **"at the beginning of the distribution system, not the end,"** says Dr. Ghatala. This means **"dropping it into the tank farm along with the petroleum-based fuels in current use."**

CBCSI partnered with the Green Aviation Research and Development Network (GARDN) to pilot the concept, using sustainable feedstocks such as canola oil, tallow or recycled animal fats as raw material for the biojet fuel.

In early 2016, Air Canada signed on as the project's official carrier. **"We have invested billions of dollars to reduce our fuel consumption and meet our emission reduction goals,"** says Teresa Ehman, Air Canada's Director of Environmental Affairs, adding that **"sustainable aviation biofuel development is important to our longer-term strategy."** Additional partners include Transport Canada, the National Research Council, Boeing, and three universities.

Why power planes with biojet fuel in the first place? Currently, about 3-4% of GHGs come from air transport. **"The only way to reduce the figure,"** says Dr. Ghatala, **"is to inject some biojet in the mix."**

MORE EFFICIENCY: CLEANER, FASTER, CHEAPER

What is stopping biofuels from full integration into Canada's energy mix? It often boils down to cost. To overcome this barrier, BFN developed models to increase efficiencies—and thereby contain costs—across the biofuel supply chain.

SHOWCASE: STRENGTHENING THE CHAIN, ONE LINK AT A TIME

A chain is only as strong as its weakest link. That is why BFN's Low-Cost Sustainable Feedstocks Task Force analyzed the links in the biofuel supply chain—a complex sequence with numerous bottlenecks—to determine how best to convey biomass from its source to the biorefinery gate.

"When people interested in running biorefineries talk to us, one of the first things they ask is, 'Where can I get enough feedstock and how much do we have to pay for it?'" says Kevin Vessey, a professor of biology at Saint Mary's University in Halifax and head of the Task Force's major initiative, called "Animating Canadian biomass feedstock supply chains."

The Task Force began by researching the pros and cons of different types of feedstock, from hog fuel and grasses to purpose-grown trees. The purpose-grown trees came out on top. **"They are an underused resource that can help biorefiners increase their supply of raw materials in a consistent and predictable way,"** says Dr. Vessey, citing hybrid poplar and willow as examples. And **"given their ability to thrive on low-quality soil, there's no shortage of land where we can grow them."**

Next challenge: how to cultivate the trees to maximize biomass yield. A method called coppicing—which involves growing trees for a year, then cutting them back and letting them regrow—got the nod from the Task Force.

Transportation poses a further problem: biomass is heavy. The Government of Nova Scotia faced this challenge in 2015, when they asked BFN for guidance in helping to attract a biorefinery. **"They didn't know how to get biomass from point A to B at a price that made sense,"** says Dr. Vessey.

After crunching some numbers, Dr. Vessey and his colleagues concluded that **"the business case for biorefineries depends on the feedstock being within 100 km of the facility. So you're looking to place a biorefinery somewhere, you need to draw a circle with a 100 km radius around it, and that's where you should be getting your feedstock."** Still on Dr. Vessey's to-do list: **"Helping the province select the best spot for a biorefinery and predicting the availability and cost of the biomass at that location."** Bottom line, **"all aspects of the value chain matter, from location to sourcing feedstock to delivering bioproducts."**

MORE INFRASTRUCTURE: LAYING DOWN THE NEW ENERGY GRID

The bioeconomy of the future will require a network of biorefineries—facilities that integrate conversion processes and equipment to produce fuels, power, heat, and chemicals from biomass—across the country. With this target in mind, BFN researchers identified optimal sites and structures for biorefineries and forged connections with industrial partners who shared their vision of an integrated Canadian bioeconomy.

SHOWCASE: OUT OF THE WOODS

It is no secret that demand for newspaper is waning. If you hop on a subway, you are more liable to see commuters staring at a smart phone or e-book rather than the "broadsheets" of times past. At the same time, businesses of all stripes are slowly but surely trading paper for electronic record-keeping systems.

These winds of change have pushed Canadian pulp and paper (P&P) mills to that proverbial fork in the road: adapt or fade out. As reported by the CBC in September 2009, more than 40,000 jobs were lost in the forest sector in the past several years. The industry continues to face strong headwinds. It has also been estimated that, indirectly, more than two jobs depend on each of Canada's 285,000 forest products jobs. BFN's Integrated Biological Biorefinery Task Force saw an opportunity to help P&P mills transition to biorefineries.

According to University of British Columbia Professor Jack Saddler and Program Manager Dr. Richard Chandra, who worked together to lead the Task Force, P&P mills have the know-how to produce high-quality, affordable bioproducts from Canadian feedstock. **"A strong P&P infrastructure already exists, so it makes perfect sense to use this asset, rather than reinventing the wheel somewhere else,"** he notes.

The traditional pulping process involves removing the glue-like lignin from wood and breaking down the remaining cellulose and hemicellulose to produce paper. BFN's biorefinery model takes this sequence up a notch by converting the sugars into a range of fuels and chemicals, while using the lignin to create high-value coproducts ranging from plastics to the carbon fibres in bullet-proof vests.

The first part of the process, called pretreatment, "opens up" the biomass to prepare it for breakdown, says Dr. Richard Chandra, the BFN researcher who pilot-tested a bioconversion process suitable for a P&P operation. Next comes hydrolysis: breaking down the cellulose into smaller sugars. The final step in the process, fermentation, helps convert the sugar to the desired end-products.

Several forest pulp companies took notice of the Task Force's work, including such world-class operations as Alberta Pacific, Catalyst, Fortress, and Port Hawkesbury. **"We've given them a model for reinventing themselves and staying healthy in a changing economy,"** says Dr. Saddler.

It is not just about dollars, though. **"We need to take a generational view of this work,"** is how Dr. Saddler sees it. **"It typically takes two to three human generations for trees to grow in Canada. Establishing a Canadian forest-based biorefinery industry may not change your life or my life all that much, but our grandchildren will surely benefit."**

FAT TO FUEL: A NEW COMPANY IS BORN

National biofuel mandates can help get biofuels into car tanks, but most companies deal with these mandates by blending biofuels into ethanol and biodiesel. David Bressler, an agriculture professor at the University of Alberta, saw an opportunity to aim higher and develop a true drop-in biofuel—a fuel made from biomass that looks and works just like petroleum-based fuel. To give life to his vision, Dr. Bressler and a group of his BFN colleagues formed a company called Forge Hydrocarbons, a company devoted to transforming low-value fats and plant oils into fuel. The company has raised $5 million in venture capital, enough seed money to develop a commercial plant. As Dr. Bressler noted, the BFN support came at a critical time in the technology development, allowing the company to leverage additional partners and link it to critical expertise.

MORE INFORMATION: THE SHARING BIOECONOMY

History abounds with examples of how science communication, or its lack, steered the course of human events. Gregor Mendel studied heredity patterns in peas in the 1860s, but it took 40 years for other scientists to rediscover his work and understand its import to humans. Alexander Fleming first came upon penicillin in the 1920s, but millions of people in World War II died of infections that could have been cured by the drug—because he did not promote his discovery; by the time other researchers tested penicillin in humans, it was too late for the war victims.

FAST FACTS

BFN invested $1.5 million in 121 Knowledge Translation activities, representing 6% of total BFN expenditures

Mindful of such "transmission failures," BFN devoted no less attention to sharing and mobilizing information than to facilitating new research. Communication activities included:

- Creating and disseminating information about biofuels through multiple media channels
- Highlighting BFN researchers' most impactful work in feature articles, many of which were picked up by national trade magazines
- Conducting stakeholder meetings and workshops, an annual Advanced Biofuels Symposium and a yearly Strategic Business Summit to establish priorities for the advanced biofuels sector
- Building trusting relationships with government stakeholders to increase engagement and reduce barriers to implementation
- Writing policy briefs (under the guidance of Warren Mabee, Professor, Geography and Planning, Queen's University to inform government and industry leaders about key issues in the emerging bioeconomy, such as the contribution of biofuels to GHG reduction, the rationale for flying green, and the extraction of biofuels from Canada's forest sector

SHOWCASE: TRANSATLANTIC TEAMWORK

In the summer of 2015, a group of clean-energy stakeholders from Europe and Canada chose Brussels—the political hub of the European Union—as the site for a workshop on developing planet-friendly, cost-competitive biofuels.

Called Renewable Carbon Sources: Processing to Fuels and Chemicals, the workshop featured presentations, panel discussions, and a "brokerage event" to jump-start collaborations between the regions. Topics ranged from sustainable feedstock to gasification to pressing needs in biofuel R&D.

When it comes to biofuels, Canada and Europe make good bedfellows. Both regions have **"the will to move forward with biofuels, particularly in transport and sustainable development,"** says BFN researcher Jean-Michel Lavoie, who helped get the summer workshop off the ground. The two zones also have complementary assets: more natural resources in Canada, and more people—meaning more minds to work on R&D—in Europe.

BFN's administrative and financial support enabled the Canadian researchers to travel to Brussels. **"Without this critical support, the workshop would have had much more limited Canadian participation and the outcome would have been a lot less meaningful,"** says Kyriakos Maniatis, Principal Administrator with the European Commission's Directorate General for Energy, who took the lead in organizing the event.

BFN delegates included engineers, biologists, and representatives from BFN industry partners such as Air Canada, Enerkem, and Éthanol Greenfield Québec. European delegates had **"about the same domains of expertise as we did, so it made for a good match,"** says Malorie Gélinas, a participant from the Université de Sherbrooke. **"It was interesting to learn how they deal with having less biomass than we do."**

Participants took advantage of breaks and meals to **"relax, meet their colleagues, and discuss the possibility of future collaborations,"** says Maniatis. **"I heard many people talk about teaming up on projects or exchanging students and postdocs."**

By the end of the workshop, everyone agreed that stronger Canada-EU ties would yield wins on both sides. Canadian companies looked forward to expanding their markets to Europe, while European companies planned to use Canadian feedstock to help them push their technologies forward.

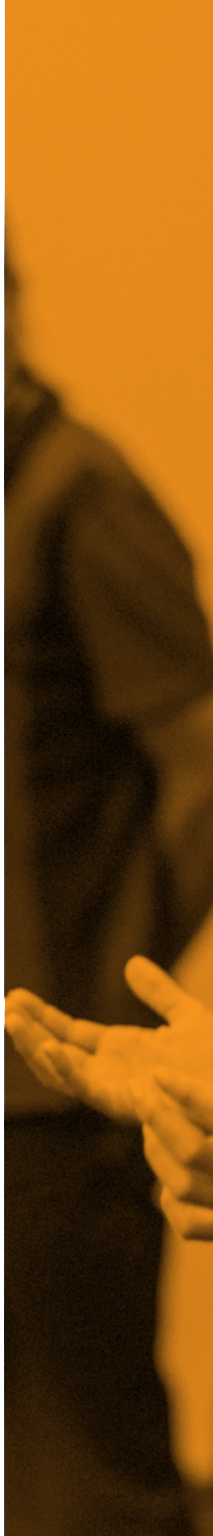
THE BIOECONOMY AND THE COMMUNITY

A group of BFN researchers is betting that biofuels can contribute to fuel security. In partnership with the University of Guelph, where project lead Naresh Thevathasan works as an associate professor, the research group launched an initiative to set up a biomass research site in Marathon, Ontario and to develop a prototype biomass-heated greenhouse that could in the future provide vegetables, berry fruits and supply heat to nearby First Nations communities in collaboration with the industry partner REMASCO. The ongoing project exemplifies BFN's commitment to use biofuels research to benefit Canadian society. Further south, researchers at Colorado State University applied BFN researchers' work to reduce emissions from fuel-flexible cookstoves targeted for remote communities.

MORE TRAINING: PASSING THE BATON

Succession planning—arranging for new leadership to replace the old guard—is an indispensable component of any strategic initiative. To ensure a continuous renewal of talent and leadership, BFN developed a robust program for training Highly Qualified Personnel (HQP)—young researchers and students with the capacity and commitment to shape Canada's future bioeconomy. Devoted to improving the quality and diversity of HQP experiences, the Network's HQP Committee:

- Gave HQP a steady stream of opportunities to engage in collaborative R&D, including collaborations with industry. About 10% of trainees signed up for industry internships.
- Balanced training opportunities across several disciplines. HQP supported by BFN included chemical and mechanical engineers, biochemists, geneticists, agriculture and forestry specialists, environmental scientists and social scientists.
- Exposed HQP to the biofuels business to fast-track their skills in strategic planning, financial projections, market analysis, and intellectual property management.
- Prioritized HQP in its funding allocations: BFN devoted about 60% of its research funds to HQP stipends, with competitive salaries that attracted the best and brightest from Canada and elsewhere.
- Allocated about $500,000 per year to HQP training initiatives such as workshops, courses, and panel discussions. Launched in 2013, the Exchange Awards supported travel to universities and laboratories for up to 3 months. Through this program, 22 HQP received specialized training at research centres throughout America and Europe.
- Devoted one day of each annual Advanced Biofuels Symposium (ABS) to HQP training, with a strong focus on developing entrepreneurial skills. At the 2015 ABS, HQP Day included a morning of public-speaking exercises facilitated by Improv Montreal. An original, "thinking outside the box" event like this even caught the attention of mainstream media (including Radio-Canada and the Montreal Gazette), raising both the profile of BFN and of the NCE!
- Sponsored and participated in the Canadian Museum of Science & Technology's Talk Energy Week (TEW) in 2015 and 2016, an initiative to encourage interest in post-secondary studies in renewable energy. BFN's HQPs presented their research to participants.



- Developed training materials, including an online Advanced Biofuels Course (ABC) and 24 educational videos and webinars on BFN's YouTube channel. Launched in 2014, the ABC covers the full cycle of advanced biofuels development and counts as a university credit. Along with HQP, the 200 people who have completed the course to date include students outside BFN, industry executives and government personnel. This part of the BFN legacy will continue beyond the NCE's initial investment.

These activities helped create a vibrant, deep-rooted community of HQP. Over the course of its mandate, BFN attracted 713 HQP, more than tripling the initial target of 212. This result attests to young researchers' strong interest in biofuels and their desire to join forces toward tangible goals.

BFN counts the HQP program among its most meaningful and rewarding achievements. In addition to boosting knowledge and skills, the program enabled HQPs to forge enduring connections with academic mentors, with industry players, and with each other.

FAST FACTS

A 2012-15 survey of BFN graduates found that:

- **Almost half** are working or studying in **Canadian universities**
- **30%** are employed in industry
- **11%** entered academia outside Canada
- **Only 5%** were looking for work


3000 mL

SHOWCASE: MORE YIELD FROM YEAST

Garret Munch radiates enthusiasm—especially when he gets a chance to talk about his passion: clean energy. **"You have to admit,"** says the University of Manitoba graduate student and former BFN HQP, **"biofuels are cool."**

When Munch began working on his Master's degree in biosystems engineering, he had his sights set on producing biodiesel. Fresh from an undergraduate degree in biochemistry, **"I was eager to apply my science background to the real world,"** he recalls. The idea of using renewable, non-edible sources for biodiesel production quickly caught his fancy. **"I was convinced it was the greatest idea since a flux capacitator was put in a DeLorean."**

Enter a little-known yeast strain called *Rhodosporidium diobovatum*, recently identified as a possibly superior source of the fatty-acid precursors to biofuels. Munch tested the strain in his lab and found it had star quality: not only did it grow very fast and produce fatty acids in abundance, but it could metabolize a number of different carbon sources, including waste from biodiesel production. **"I liked the idea of putting waste to good use,"** says Munch. **"Especially when it 'closed the loop' on the biodiesel production process so neatly."**

So did his supervisor, University of Manitoba engineering professor Dr. Nazim Cicek, who advised Munch to scale up the process to test its possible commercial potential. A BFN exchange grant allowed Munch to spend eight weeks in the lab of Dr. Lars Rehmann, a Western University professor whose chief interest lay in optimizing bioreactor performance. Drawing on Dr. Rehmann's experience and equipment, Munch ramped up his process to a 100-L pilot-scale reactor system. He breathed a sigh of relief when his yeast aced the test.

Back at the University of Manitoba, Munch and his colleagues plan to expand the project to optimize fatty acid production and possibly explore extracting high value co-products from the yeast. Ideally, **"we can eventually link up with a biofuel production company that generates the waste we use for future studies on-site,"** says Dr. Cicek—a win-win scenario if ever there was one.

LOOKING AHEAD

BFN may have wrapped-up its NCE mandate, but the engine it set in motion continues to run. BFN researchers continue to interact, to collaborate on projects, to file patent applications, and to partner with industry to put biofuels on the Canadian energy map. Government stakeholders continue to participate in the national conversation about biofuels. Thanks to the NCE's vison and investment in BFN, the genie is out of the bottle! As a lasting legacy for Canada, BFN's work goes on to maintain the momentum of the NCE's investment for years to come.

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