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STRATEGIC PLAN 2020

Industrial Systems Optimization Group

CanmetENERGY-Varennes

Canada

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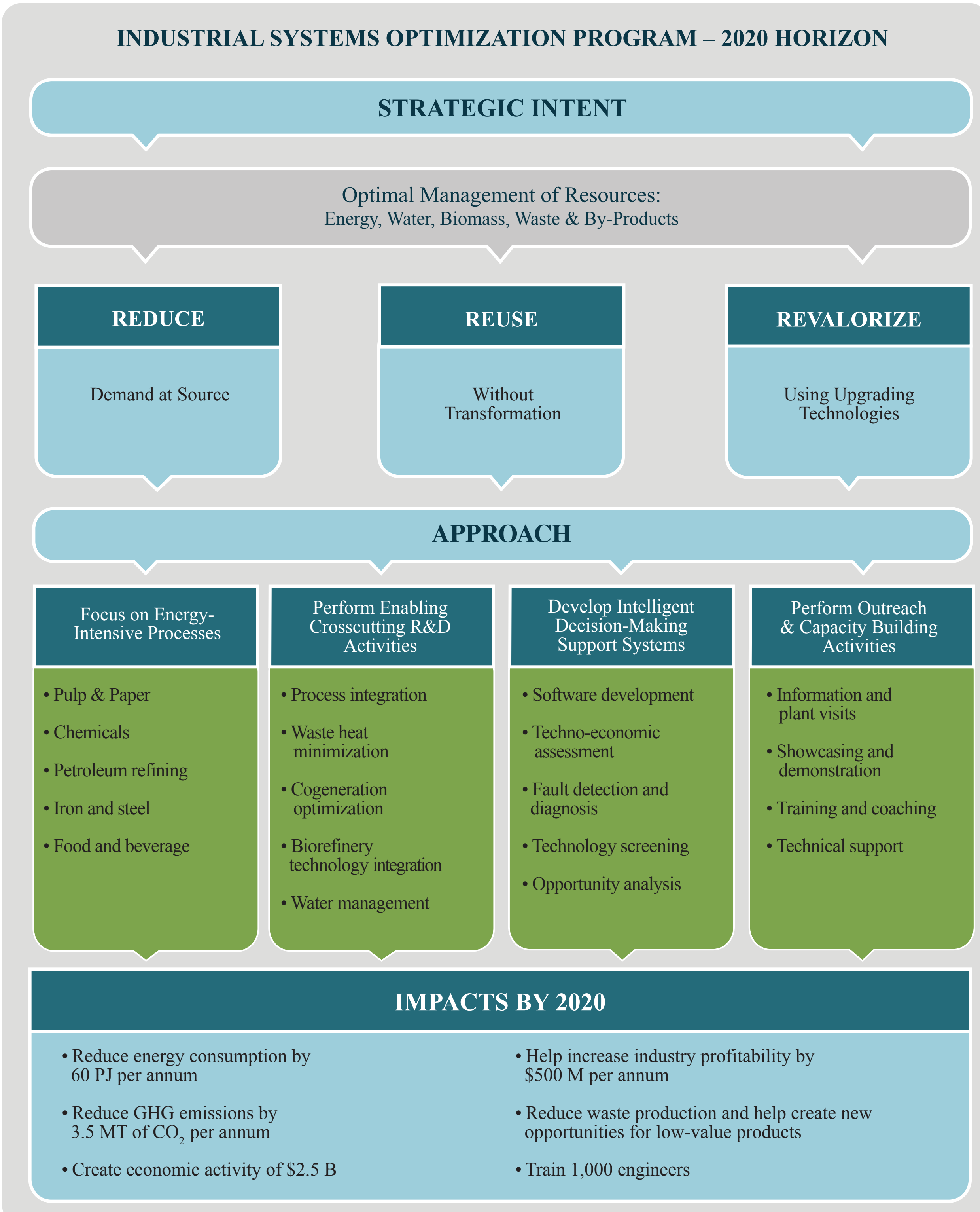

Figure 1: Industrial Systems Optimization Program – 2020 Horizon

The Challenge

The challenge for Canada is to develop an approach to industrial energy which aligns its socio-economic and environmental imperatives in a more coherent fashion.

With sustainability as a new business driver, the ultimate challenge for large-scale industrial systems optimization is to reconcile the three pilars of sustainability, namely economic, environment and social aspects (**Figure 2**). By dramatically increasing the productivity of natural resources through fundamental changes in both production design and operation, industry can reduce the waste of energy, water, materials and other resources, and create more value through its production system and other operations. This represents a major business opportunity for the Canadian industry which, in turn, comes with the need of thoroughly understanding the impact of these changes on the overall company operations.

Figure 2: Typical Plant Issues and Challenges

Our value proposition is to provide Canadian energy-intensive industrial sectors with Whole-System Design tools and knowledge to improve their global efficiency, increase their competitiveness and reduce their environmental footprint.

"A systems approach is essential to maximizing the benefits of energy technologies and effectively managing energy innovation. This approach should be supported by the data and intellectual capacity needed to analyze energy systems." [1]

"Industrial process optimization can save up to 50% of energy use in Canadian industry, which accounts for 32% of all energy use while reducing emissions in disruptive processes." [2]

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[1] NATURAL RESOURCES CANADA. "Powerful Connections, Priorities and Directions in Energy Science and Technology in Canada", The report of the National Advisory on Sustainaible Energy Science and Technology. Office of Energy Research and Development. 2006, p. 9.

[2] NATURAL RESOURCES CANADA. "Opportunities for Canadian Energy Technologies in Global Markets". [Electronic document]. McKinsey & Company report. 2012. http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/files/pdf/2013/McK-Report-eng.pdf

Our Approach

The Industrial Systems Optimization Program develops, manages, and implements a robust portfolio that addresses industrial requirements throughout the technology development cycle (Figure 3).

- High-return R&D projects are the foundation of the Industrial Systems Optimization Program. Program efforts are balanced with respect to risk and timeframe, and aligned with industrial and Government needs and priorities.

- Validation and verification of technological benefits, through intermediate-term pilot and demonstration phases, help emerging technologies and tools reach commercialization and near-term adoption.

- Dissemination of energy efficiency technologies and practices is accomplished through a variety of information and technology delivery vehicles with the assistance of NRCan's Office of Energy Efficiency (OEE), provincial governments and utility companies. These activities help industry reap the benefits of proven technologies through information and customer decision tools, training, and strategic partnerships.

- Capacity building efforts are also an integral part of our approach to strengthen the skills, competencies and abilities of stakeholders and decision-makers in achieving measurable results. Working closely with universities also allows our innovations to be incorporated into the learning process of a new generation of engineers and managers.

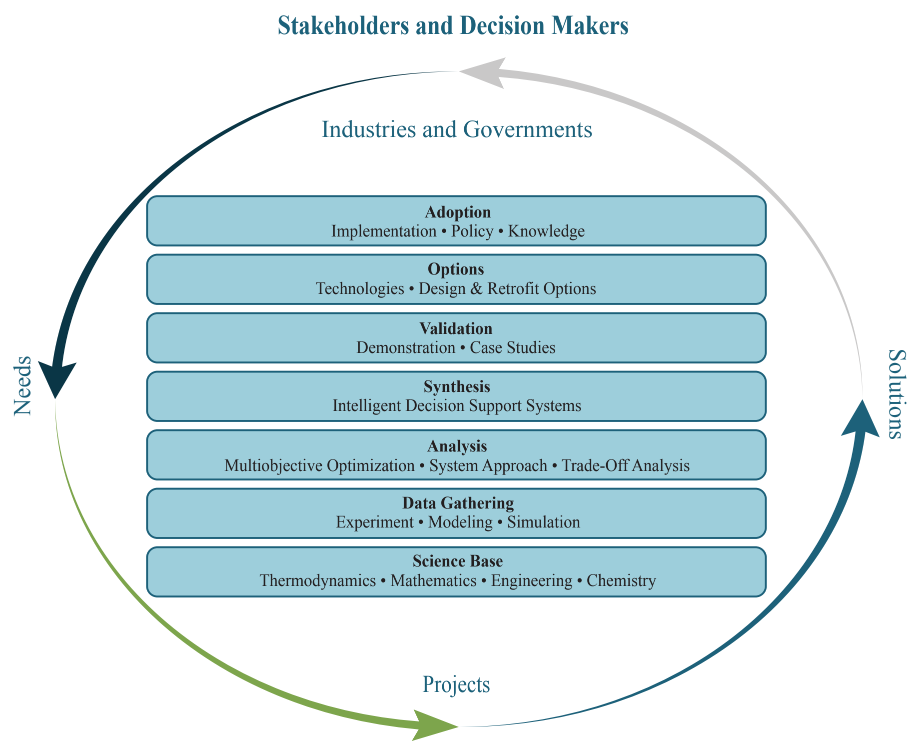


Figure 3: Value Creation Approach

Industrial Systems Optimization Program

CanmetENERGY-Varennes leads Industrial Systems Optimization delivery within the Federal Government, serving as a provider and catalyst for a sustainable energy future for Canada.

CanmetENERGY within Natural Resources Canada (NRCan) is the largest energy science and technology (S&T) research Centre in Canada. Its activities range from research to late-stage technology development, demonstration and deployment. We provide innovative solutions in the form of knowledge, software tools, guidelines, workshops and technical support to the industry and governments (**Figure 4**).

The Industrial Systems Optimization Program focuses on innovative plant-wide industrial process analysis and optimization techniques, such as Process Integration (PI) and Data Mining (DM) to identify and correct inefficiencies in plant design and operation. It also helps in introducing new technologies for improved heat recovery and biorefinery implementation, with due consideration for natural resources, energy, economic and environmental factors.

The CanmetENERGY-Varennes Industrial Systems Optimization program develops knowledge and tools necessary to demonstrate and deploy process optimization methodologies in industrial plants to achieve an efficient use of resources.

Our group offers a unique set of skills in the area of industrial systems optimization – a combination of process modeling, process simulation and mathematical optimization tools for site-wide optimal management of energy, utilities, water and chemicals. Together, along with the best strategic alliances and innovation practices, we create high value for our partners and customers.

Figure 4: Our Products and Services

Research & Development Activities

CanmetENERGY promotes the use of a comprehensive approach to improve the energy efficiency of industrial processes at both the design and operational levels. A global approach consists in analyzing a process as a whole rather than considering individual operations independently. This method can be used to reduce energy consumption through increased heat recovery, maintain energy performance over time or support the optimal integration of new technologies.

Our scientists investigate energy management improvement opportunities for industry by using a global approach. The improvements can result from the recovery and use of rejected heat, from optimized control based on process modeling, or from the use of new technologies (e.g. condensing heat exchanger and turbines, biomass lignin extraction, etc.).

Our experts and industry partners rely on our analysis tools not only to examine the individual equipment / processes, but also to study how they interact. This is done in order to reduce global plant consumption and production cost, improve overall operations and maximize investment strategies.

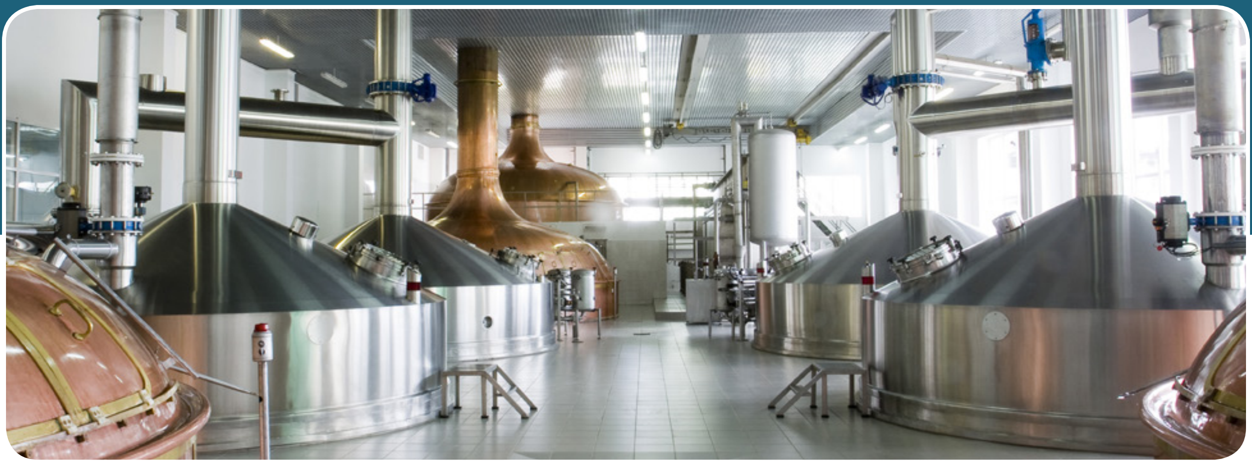
The main ongoing and early-stage research and development activities address the following areas:

- **Heat management**
- **Combined heat and power (cogeneration)**
- **Forest biorefinery**

These activities, which primarily target energy-intensive sectors and industrial processes, are aimed at developing innovative and transversal approaches adaptable to multiple industrial sectors. The following sections describe each area of research in greater detail.

Heat Management Program

The Heat Management Program develops knowledge and tools to minimize industrial waste heat generation and support the use of advanced heat recovery and upgrading technologies.



RATIONALE AND NEEDS

Most of the energy entering the boundaries of an industrial facility as input to the production processes is eventually rejected to the environment as "waste heat" in various types of stream and at various temperature levels (**Figure 5**). As energy inputs work their way through processes, the quality of that energy is degraded and "waste heat" is produced. In numerous plants, part of this waste heat is already captured and reused. However, non-optimal design and operation of processes still exist and the unrecovered waste heat therefore represents an important cause of excessive energy use in industry. Influential studies[3-4] identify "waste heat" as a significant untapped energy resource. These same analyses indicate that between 10 and 40% of the currently unrecovered waste heat can be cost-effectively recovered and, when combined with disruptive technologies, can result in energy savings as high as 50%.

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3 U.S. DEPARTMENT OF ENERGY (DOE). "Energy Loss Reduction and Recovery in Industrial Energy Systems, Technology Roadmap". Office of Energy Efficiency and Renewable Energy, Energetics Inc., 2004, 55 p. [Electronic document]. http://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/reduction_roadmap.pdf

4 INTERNATIONAL ENERGY AGENCY (IEA). "Energy Technology Perspectives 2012 - How to secure a clean energy future". [On-line]. http://www.iea.org/etp/etp2012/

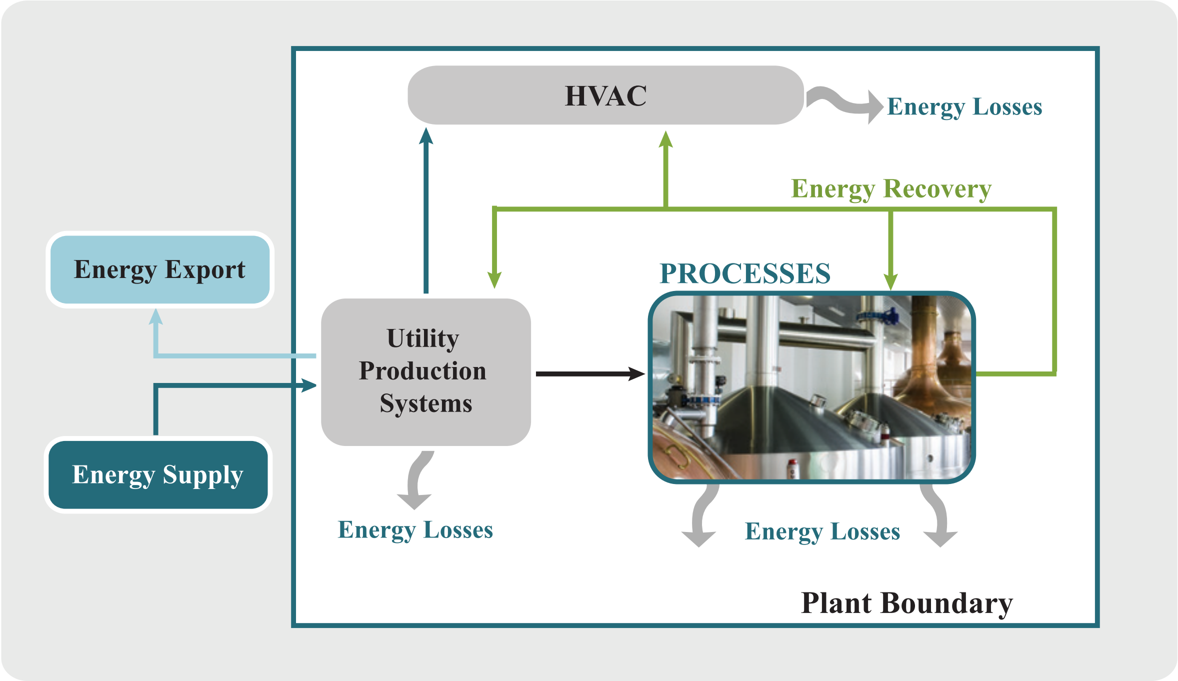

Figure 5: Energy Use and Recovery in Industrial Plants

From an industrial perspective, minimizing heat losses and improving heat recovery are among the top priorities when it comes to reducing operating costs through energy efficiency. However, maximizing the benefits requires, on the one hand, advanced methodologies to identify optimal heat recovery solutions and, on the other hand, the implementation of suitable technologies.

Since industrial processes are complex and involve numerous heat sources and heat demands from various loads and temperatures, the effective management of heat across an entire facility is a daunting task. How can the best heat recovery solutions be systematically identified? What technology should be considered? How can heat be recovered under harsh conditions? What is the potential for heat pumps and power generation technologies? How can energy-intensive systems be better managed to reduce waste heat generation? How can high operational performance be maintained over time?

For industries, the answers to these questions require a deep understanding of how energy is being used throughout the plant, and advanced decision support tools to optimally design and operate processes. For governments and legislators, this will contribute to creating effective policy frameworks and programs for taking advantage of the huge potential offered by industrial waste heat recovery.

Approach

In industrial sites, sub-optimal process designs, past-generation technology use, non-optimal operating conditions and the difficulty to maintain equipment and process performance over time are the main causes of excessive energy use.

In order to better manage thermal energy consumption and improve plant performance, an integrated approach that addresses technology, design and operational aspects is proposed (**Figure 6**). Such an approach consists of:

- **Optimizing heat recovery network systems** by analyzing where thermal energy is being used, where waste heat is generated, where energy can be recovered using the most appropriate technologies, and what would be the best use for that heat to improve site profitability. This analysis ensures that processes are optimally designed with respect to energy consumption while taking into account process and economic constraints as well as equipment selection considerations.

- **Improving process operations and maintaining high performance over time** by monitoring and analyzing key performance indicators that will help plant personnel identify optimal operating conditions, reduce variability, better manage abnormal situations and continuously run their processes in the most efficient and profitable way.

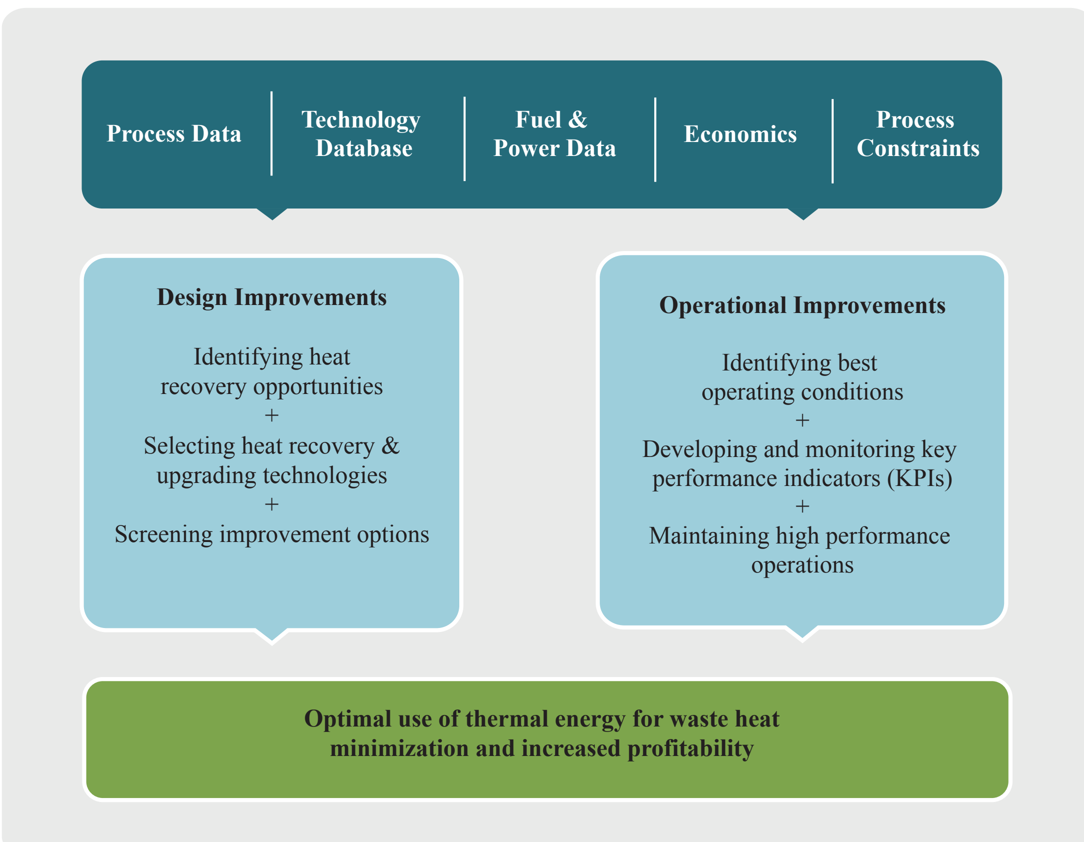

Figure 6: Integrated Approach to Efficient Heat Management

Along with Canadian partners involved in industrial energy research and innovation, CanmetENERGY is working to develop innovative solutions to better manage thermal energy usage in an integrated fashion. CanmetENERGY brings a comprehensive expertise in the area of process design, simulation and optimization. This is achieved by a number of specific activities that include:

Mapping waste heat sources and heat recovery potential:

- Surveying typical Canadian plants to develop a detailed mapping of energy flows, waste heat sources and heat recovery potential
- Analyzing waste heat sources and available technologies
- Identifying technology gaps for the recovery of waste heat streams

Developing effective decision making tools:

- Developing templates and key performance indicators to simplify and accelerate data collection from common processes and equipment items
- Building a techno-economic database of established and novel heat recovery and upgrading technology models for project screening and assessment, including heat exchangers, heat pumping, waste heat-to-power generation such as organic Rankine (ORC) or Kalina cycles and others
- Developing systems engineering tools to reduce thermal energy use and maximize operating profits in complex industrial processes by:
    - Analyzing current process performance, and identifying sources of thermal inefficiencies and where energy improvements can be made
    - Optimizing heat recovery systems using established and novel technologies that reduce energy use and waste heat generation
    - Improving complex water networks with direct energy implications
    - Reducing operational variability and managing abnormal situations using historical data analysis, and developing strategies that maintain high performance over time

Knowledge and technology transfer:

- Embedding the most recent advances from our Heat Management research program into CanmetENERGY's **INTEGRATION**[5] and **EXPLORE**[6] software tools for improving heat usage at equipment, process and facility levels
- Working with industry and other partners to validate and demonstrate the newly-developed software tools to identify, screen and select advanced heat management solutions and technologies
- Promoting the adoption of the developed tools to energy consulting companies, engineering firms, industrial plants and universities using existing NRCan deployment mechanisms
- Developing sector-specific roadmaps and technical guides for the retrofit of existing facilities and the conceptual development of the so-called "process of the future" in pulp and paper, oil refining, food industries and others
- Providing government policy and program developers with relevant knowledge for the implementation of optimal heat recovery as well as upgrading and management solutions in Canadian industries
- Disseminating the scientific and technical outputs at both the national and international level

The ultimate objective of our Heat Management Program is to provide industry with decision making tools that will help select design and operational improvements to reduce heat losses and improve their energy profile over time. This will be achieved through extensive collaborative work as well as outreach and capacity building efforts[7] to disseminate the knowledge, know-how and tools to make more profitable decisions on how to reduce energy consumption and improve profitability.

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5 CanmetENERGY develops software tools to better manage energy use and power generation in complex industrial facilities. **INTEGRATION** improves heat recovery and reduces thermal energy use in process industries. A built-in database of technology models helps select and evaluate heat recovery, heat pumping and waste heat-to-power technologies.

6 **EXPLORE** improves process operation by reducing variability. Built-in diagnosis capabilities help detect and correct abnormal situations, therefore maintaining processes and equipment at their maximum efficiency over time.

7 Refer to the Outreach section of this Strategic Plan.

Benefits

Reducing heat demand is one of the most cost-effective ways to reduce operating costs in energy-intensive industries, notably when both operational changes and design improvements are considered in a synergetic way. In situations where the recovered heat is used to generate electricity through the site cogeneration system or through waste heat-to-power systems, this electricity can represent a new source of revenue when sold to the grid.

For a typical Canadian plant, optimizing the thermal energy consumption using an integrated approach for improving and maintaining plant energy performance over time generates energy savings of 10 to 40% with a payback period between 1 and 4 years. In medium-sized industries, cost reductions of several hundred thousands of dollars can be obtained annually. In large-scale industrial facilities, this means improving their bottom line by several millions of dollars annually.

Combined Heat and Power Program

The Combined Heat and Power Program develops tools and knowledge to support the optimal design and operation of industrial heat and power systems. It will contribute to industry's transformation toward highly efficient and profitable energy systems.

Rationale and Needs

Combined heat and power, also referred to as CHP or cogeneration, is the simultaneous production of heat and electricity from a single fuel source, at or close to the end use. By using the heat output from the electricity production system for process applications, substantial gains in energy efficiency can be realized. The separate production of heat and power typically has an overall efficiency of 50-60%, while CHP plants are able to reach an efficiency of 75-85% (**Figure 7**).

Another important advantage of CHP is the increased reliability of energy supply and the absence of transmission losses associated with electricity purchase via the grid. In spite of these advantages, CHP has had a low market penetration in Canada thus far – except in the pulp and paper and petrochemical industries – which means a large potential is yet to be exploited.

With the deregulation of energy markets, where an industrial plant can be both a consumer and producer of electricity, and with the increased volatility of energy prices, these advantages have recently led to a growing interest in CHP technologies among energy customers, providers and legislators.

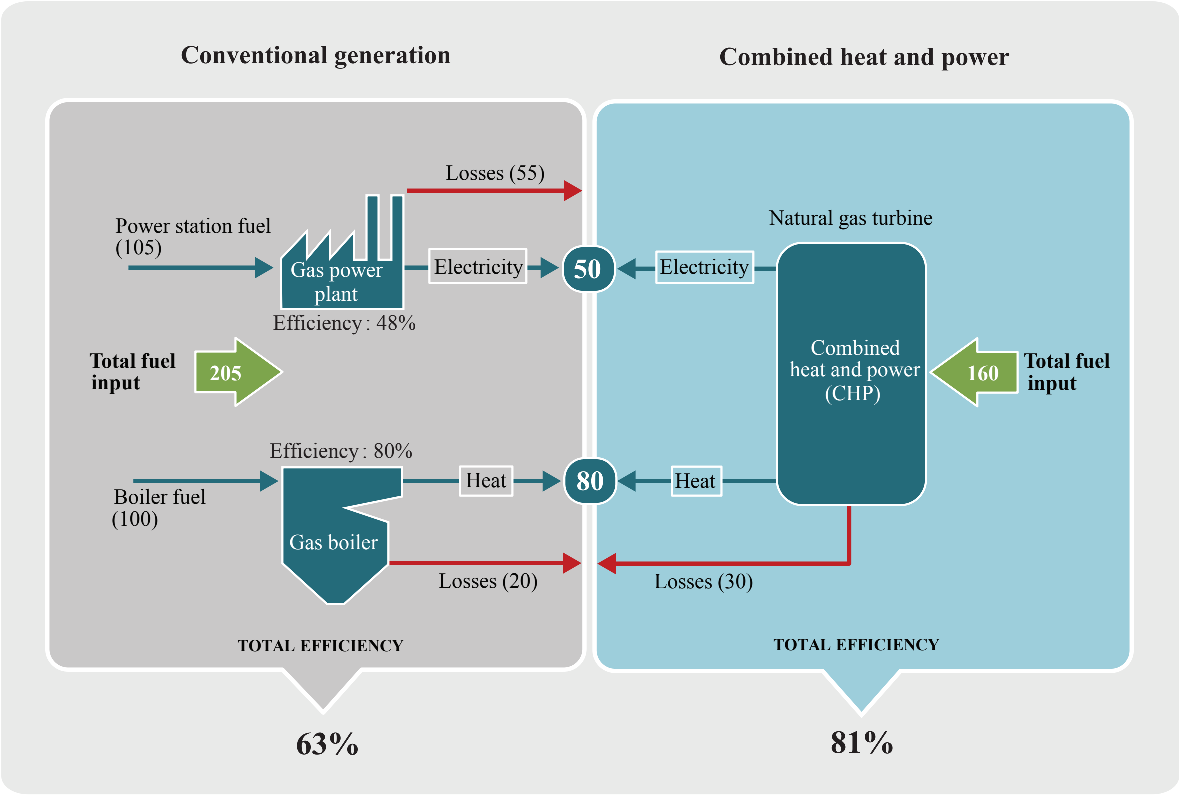

Figure 7: Example of CHP Efficiency Gains

Most industrial CHP systems are designed to meet heat and power average loads. Because of the continuous fluctuation in the plant steam and electricity usage, and the implementation of energy efficiency projects, the performance of these systems can be negatively affected over time. Furthermore, operating constraints of the CHP system may limit the implementation of energy efficiency projects. In such situations, operating a CHP system in the most efficient and profitable way is far from obvious.

Ensuring that process operations receive reliable heat and power supplies while minimizing energy costs is a complex task involving several aspects: How does improved heat recovery across the plant affect the CHP system? Which boilers and turbines should be operated, at what load and using which fuel? How much electricity should be imported from the grid and how much should be self-generated? What strategy should be considered to achieve the lowest steam and power production costs, maximum reliability and reduced environmental impacts? How can abnormal situations be better managed and CHP system performance maintained over time?

For industrial plants, the answers to these questions require advanced decision support tools to optimally design and operate CHP systems while considering technical, production, contractual and reliability constraints. For governments and legislators, the answers to these questions will contribute to creating effective policy frameworks and programs for developing and promoting CHP application as part of the country's energy infrastructure.

Approach

Given the complexity of industrial plants with numerous operations and interactions between process and utility systems, a holistic and systematic approach is needed to achieve maximum energy efficiency and profitability (**Figure 8**). Ideally, process units should be optimized first through increased heat recovery and operational improvements to reduce the process steam demand. The steam savings can then be turned into a reduction of fuel usage in the boilers or used to produce more power out of the CHP system[8].

In order to run CHP systems in the most efficient and profitable way, it is necessary to:

- **Optimize CHP systems** by selecting the best operating conditions while taking into account process, economic, reliability, environmental and equipment constraints. This offline analysis can be done for each production context to improve utility system design as well as for operation planning.

- **Maintain high performance over time** by developing, monitoring and analyzing key performance indicators to understand inefficiencies, reduce variability and better manage abnormal situations. Providing operators with decision support tools will allow them to act rapidly and to continuously run the CHP system in the most efficient and profitable way.

[8] Refer to the Heat Management Program section of this Strategic Plan.

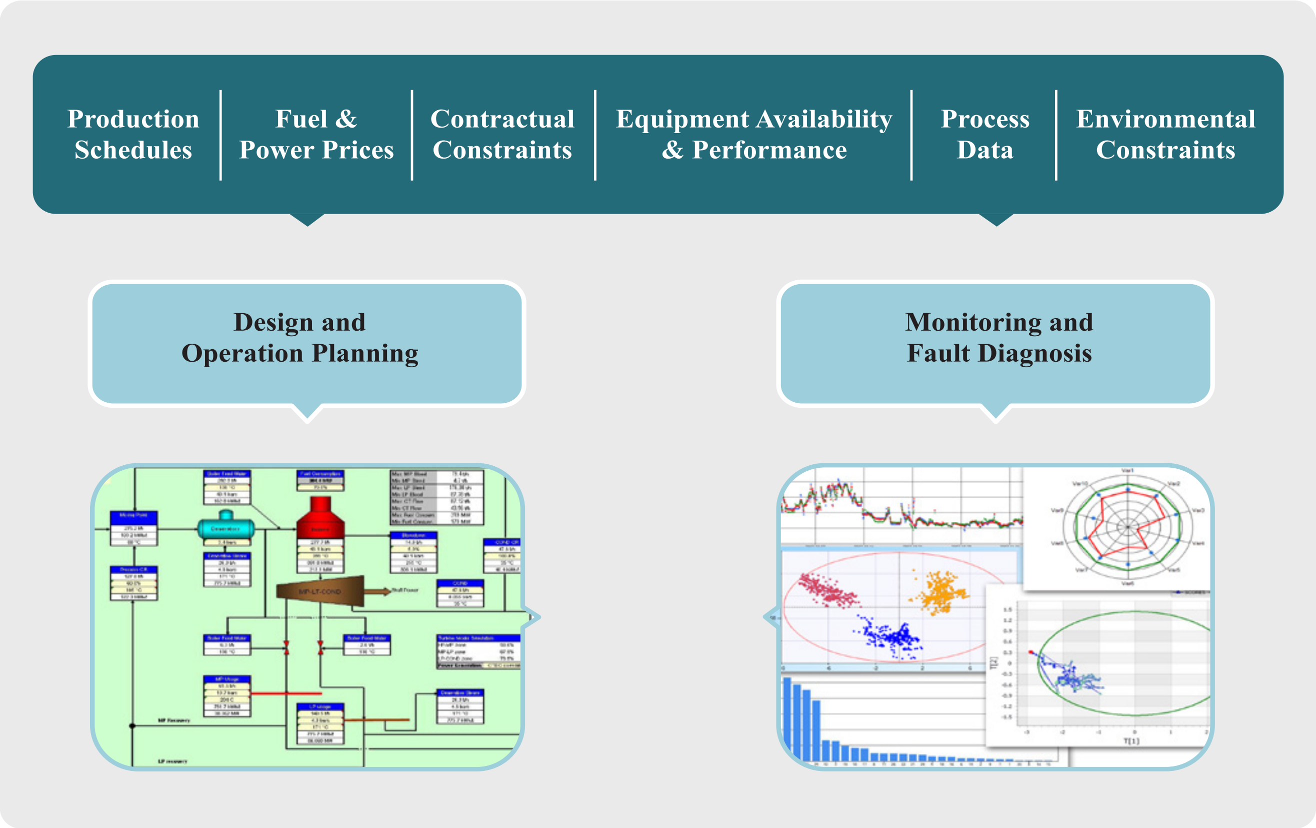

Figure 8: General Approach to Highly Efficient CHP Systems

Along with Canadian partners involved in industrial innovation and CHP applications, CanmetENERGY is working to develop solutions that help optimize heat production and power generation in process industries. CanmetENERGY brings a comprehensive expertise in the area of process design, simulation and optimization to support the implementation of CHP systems in Canadian industries. This is achieved by a number of specific activities that include:

Mapping existing CHP systems and identifying new opportunities:

- Conducting market assessments to identify existing CHP systems and quantify heat and power generation in Canada
- Identifying the most promising industrial CHP opportunities
- Estimating potential electricity sales, energy savings and emissions reductions obtained through optimally designed and operated CHP systems

Development of CHP roadmaps and effective decision-making tools:

- Developing templates to simplify and accelerate data collection from utility systems and key processes
- Developing innovative algorithms and engineering tools to optimize CHP systems design and operation by:
  - Predicting how CHP systems respond to operational or configurational changes
  - Minimize CHP system operating costs under equipment, environmental, financial and energy supply-related constraints, considering current or future process demands (utilities production planning)
  - Evaluating heat recovery opportunities between site processes and CHP systems to further improve plant energy performance
  - Determining the most beneficial design options for new equipment in case of plant expansion, equipment replacement or installation of a new CHP system (investment planning)
  - Conducting demonstration projects to maximize overall benefits considering purchased energy and power sales, under a range of constraints

Development of decision support tools for efficient CHP system operation:

- Turning available data into useful information that helps operators in assessing process status and determining optimal states
- Developing key performance indicators and predictive models
- Monitoring the whole CHP system performance
- Automatically detecting and diagnosing CHP system inefficiencies and abnormal situations (faults)
- Providing information to operators to rapidly correct abnormal situations

Knowledge and technology transfer:

- Embedding the most recent advances from our Combined Heat and Power research program into CanmetENERGY's **COGEN**[9] software for improving industrial power generation systems
- Transfering the knowledge and tools to empower plant personnel to proactively manage their operations
- Developing sector-specific roadmaps for implementing CHP systems in Canadian industry considering technology, operation, and energy supply contract options
- Working with industry and other partners to demonstrate and validate newly developed tools for best implementing integrated CHP systems in existing or new facilities
- Providing policy and program developers with relevant knowledge to maximize impacts from industrial CHP systems in Canada
- Developing and delivering topical courses on CHP optimization for industrial and academic partners
- Disseminating scientific and technical outputs at both the national and international level

The ultimate objective of our Combined Heat and Power Program is to develop systems engineering tools and strategic roadmaps that will help facilities across the country invest in CHP, providing affordable and reliable power and heat while ensuring efficient operation. This will be achieved through extensive collaborative work as well as outreach and capacity building efforts[10] to actively disseminate the knowledge, know-how and tools to make more profitable decisions on how to use and supply energy in industrial systems.

[9] CanmetENERGY develops software tools to optimize thermal energy use and power generation in complex industrial facilities. **COGEN** includes systems analysis capabilities to quickly model, simulate and optimize the operation and design of industrial combined heat and power systems and their associated steam and condensate return systems.

[10] Refer to the Outreach section of this Strategic Plan.

Benefits

Cogeneration is a way of efficiently and simultaneously producing heat and power that offers significant value for industrial facilities. For a plant that implements a new CHP system, a higher overall efficiency generates significant energy savings. Additional revenue streams can also be generated by selling power to the grid, and these benefits are particularly interesting when "green electricity" is produced using biomass, a renewable resource.

For a plant that operates an existing cogeneration system, optimizing and maintaining the CHP system performance over time is a low-cost approach to reducing energy costs and improving profitability.

For a typical 40 MW CHP plant, an optimized system typically generates energy savings of 3% and increased power generation by 3%. Overall, this represents economic benefits of $1.5 million and a total greenhouse gas emissions[11] reduction of 10,000 tonnes annually with a payback time of less than one year. When new cogeneration schemes are evaluated involving capital projects, cost savings of up to 20% can be obtained. An average of 5% in additional operating cost reductions can also be obtained by monitoring performance, quickly detecting faults, and improving the planning of shutdowns and start-ups.

[11] Total greenhouse gas emissions (GHG) include direct and indirect emissions. Direct GHG emissions are those associated with fossil fuel usage in the CHP system while indirect emissions are related to the electricity produced by the CHP system.

Biorefinery Program

The Biorefinery program develops integrated biorefinery pathways, knowledge and tools to support the development and optimal integration of biorefinery technologies into existing or new industrial value chains that will lead the industry's market transformation toward bioeconomy.

Rationale and Needs

Canada's forest industry is now refocusing its business model toward so-called bioeconomy to take advantage of Canada's abundant, high-quality and renewable forest resource. Led by the Forest Products Association of Canada (FPAC) through its "*Vision 2020, Canada's Natural Advantage*" [12], work is underway to develop technologies, processes and business models to produce innovative green products from forest biomass and extract more value from every tree harvested. This can be achieved by producing high value bioenergy, biochemicals and biomaterials in addition to traditional lumber and pulp and paper products. This is expected to represent an additional $20 billion in economic activity and strengthen the sector's competitiveness, jobs and communities across Canada for the long term.

[12] FOREST PRODUCTS ASSOCIATION OF CANADA (FPAC). "Vision 2020, Canada's Natural Advantage". [Online]. http://www.fpac.ca/index.php/en/page/vision2020

A number of initiatives conducted by FPAC, FPInnovations and CanmetENERGY examined the market potential of emerging bioenergy, biochemicals and bioproducts. These initiatives have flagged that pulp and paper mills are an ideal platform for the demonstration of the biorefinery concept because of their scale, existing infrastructure, proximity to biomass sources, and experience in biomass logistics. Forestry companies are increasingly moving forward and establishing their biorefinery strategies to identify competitive and promising bio-based products, as well as suitable technologies for their production. However, many potential product opportunities make this decision rather difficult. Therefore, understanding which products to make, and how to make them most effectively with minimum technological, market, financial and environmental risks, is critical.

A number of key questions must be answered to support the decision making: Which products will consumers want or need? Which purity or performance levels are needed and at what price? Which co-products could be considered? What are the available processes? What is the best way to integrate these new processes into existing infrastructure to minimize impacts on process operations, as well as on energy, water and raw material usage? How to bridge forest industry with chemical industry?

The answers to these questions will require the development of advanced decision support tools to maximize return on capital employed while minimizing risks of future investments in industry. For the Government of Canada, this will contribute to finding the best place to invest R&D dollars, and creating a stable and long-term policy framework for biofuels, biochemicals and biomaterials to increase investors' confidence and allow for the expansion of bioeconomy.

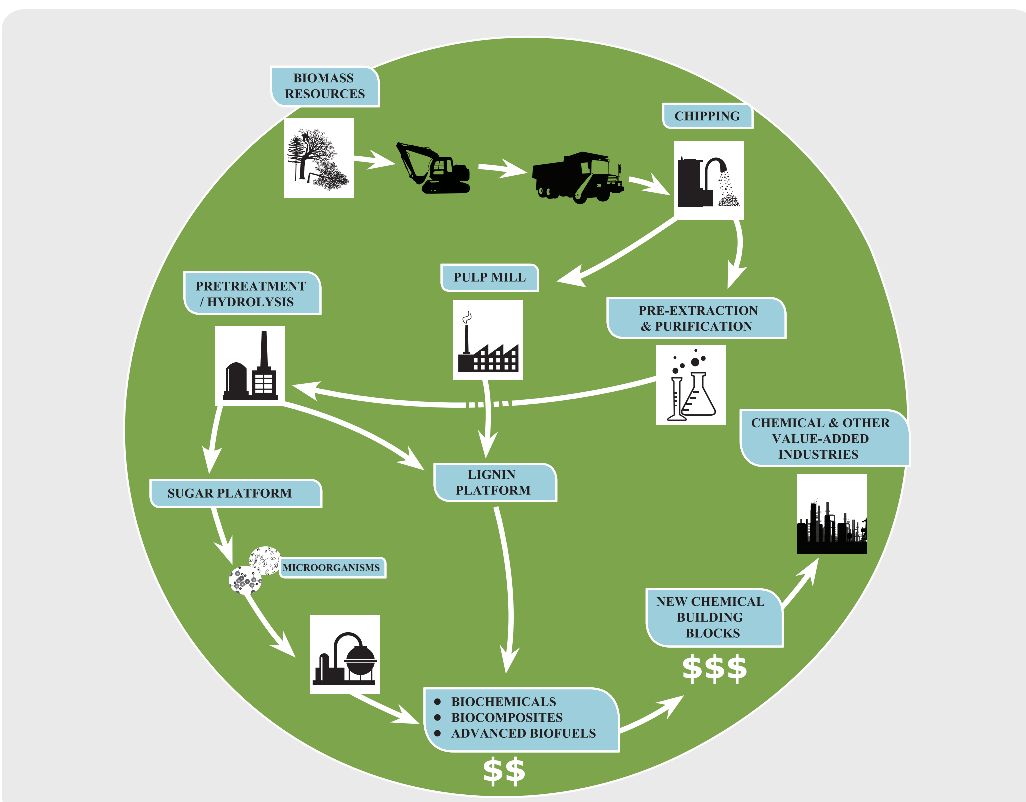

Figure 9: Innovation Pathways Towards Biorefineries

Approach

To make possible the use of lignocellulosic biomass as feedstocks (such as forest and agricultural biomass) for bio-based products production, it is necessary to fractionate it into valuable streams using several possible technology platforms (**Figure 10**):

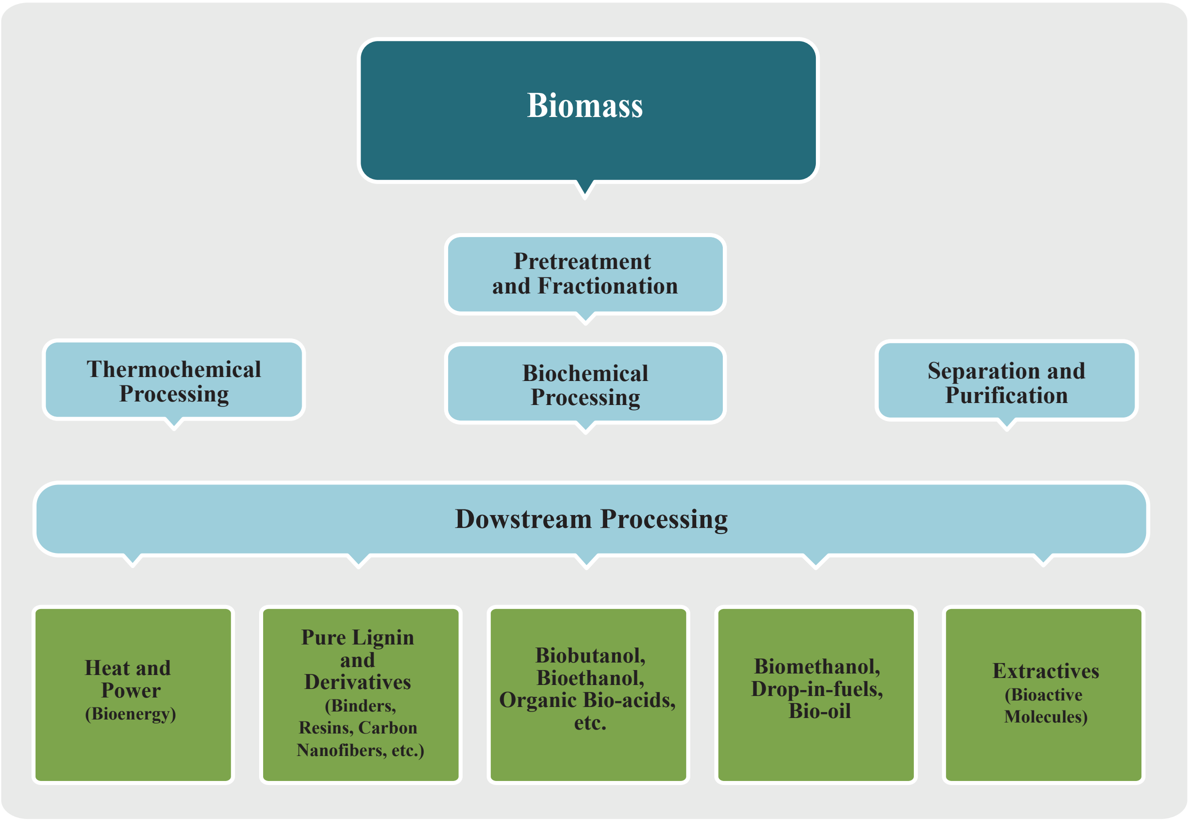

Figure 10: Integrated Biorefinery – Extracting More Value from Biomass Resources

Pretreatment platform: where the lignocellulosic biomass is pre-processed and fractionated into lignin, hemicellulose and cellulose streams for further processing.

Lignin platform: where lignin is extracted and purified to the level needed for the targeted application (e.g. moderate purity as an energy source for existing combined heat and power systems and for lime kilns within mills, or high purity as feedstock for biocomposites and adhesives).

Sugar platform: where cellulose and hemicellulose are hydrolyzed to produce sugar-rich streams which are thereafter biochemically converted into a portfolio of potential biochemical products, including biobutanol as a chemical precursor for many derivatives or as transportation fuel or organic bio-acids (lactic, succinic, etc.) as green chemical building blocks.

Thermochemical platform: where biomass is thermally converted into syngas through gasification or bio-oil trough pyrolysis, and thereafter transformed into methanol, alcohols, and drop-in fuels.

Along with Canadian and international partners involved in the biorefinery innovation chain, CanmetENERGY is working to develop, evaluate and optimize biorefinery solutions that maximize the value from the biomass resource using its components to produce a variety of co-products. CanmetENERGY brings a comprehensive expertise in the area of process design, simulation and optimization as well as technology assessment to support and guide the incremental implementation of biorefinery technologies. This is achieved by a number of specific activities that include:

Mapping and optimization of resources utilization in existing industrial production systems:

- Optimizing existing assets to better serve as a platform for new biorefinery technologies by improving energy, water and power production efficiencies
- Developing detailed and optimized simulation models of biorefinery processes that maximize conversion efficiency and minimize the use of energy, water and other resources
- Evaluating the technical strategies to compensate the resource demands due to biorefinery implementation within existing industrial value chain

Developing biopathways and retrofit design solutions:

- Evaluating the impacts of novel processing pathways on current plant operations and providing strategies to minimize possible negative impacts
- Modeling stand-alone and integrated biorefineries producing at least one key product with or without a series of co-products
- Developing protocols and guidelines for the integrated design of innovative biorefinery technologies and cost-effective implementation into existing industrial infrastructure
- Adapting Life Cycle Assessment (LCA)-based metrics to assign biorefinery products to their best uses
- Developing cost-effective biopathways for an optimal use of Canadian biomasses considering bioenergy and bioproduct options
- Defining multi-criteria decision-making (MCDM)[13] protocol to reflect different perspectives for comparing possible process options in order to identify the preferred ones
- Developing a hierarchical design framework, incorporating systems engineering tools for decision-making

[13] MCDM is a Multi-Criteria Decision Making tool, developed by École Polytechnique de Montréal in collaboration with CanmetENERGY-Varennes, which combines and applies thermodynamic and economic models to design biorefinery technology options. A MCDM is often driven in cooperation with industrial panellists to screen biorefinery alternatives, define criteria and related metrics, and rank them rigorously.

Knowledge, know-how and technology transfer:

- Embedding the most recent advances from our Biorefinery research program into CanmetENERGY's **I-BIOREF**[14] software for the techno-economic and environmental assessment of biorefinery technology options
- Working with industry and other partners to validate and demonstrate the novel products/processing pathways of sugar-rich streams and lignin
- Working with industry to turn biorefinery research, development and innovation into a reality
- Conducting a series of workshops with industry stakeholders to explore different aspects of integrated biorefineries
- Developing and delivering topical course material for academic and industrial partners
- Developing a specific program to train the leaders of the future biorefinery industry
- Disseminating scientific and technical outputs at both the national and international level

In the short term, our activities focus on the integration of small-scale biorefinery processes into existing infrastructure to gain experience and minimize risks while increasing knowledge on how to model, design, select and best integrate biorefinery technologies. In the longer term, our work will be expanded toward the development of a stand-alone integrated technology platform for the production of lignin and its derivatives, sugar-derived biochemicals and co-products.

The ultimate objective of our Biorefinery program is to develop optimal biopathways from forest and agricultural biomass that will lead to industry's market transformation. This will be achieved through extensive collaborative work as well as outreach and capacity building efforts[15] to disseminate the knowledge, know-how and tools to make more reliable decisions that best respond to market demands for bioproducts and biomaterials.

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[14] I-BIOREF software tool was developed by CanmetENERGY to quickly evaluate the economic viability and environmental impacts of integrating various biorefinery strategies into existing pulp and paper mills. I-BIOREF includes capabilities to evaluate the benefits of integrating commercially available processes for pretreatment, lignin, sugar and thermochemical platforms; to perform sensitivity analyses on various parameters; and to evaluate environmental impacts using LCA-based metrics.

[15] Refer to the Outreach section of this Strategic Plan.

Benefits

Biorefineries integrated into pulp and paper mills may reduce bioproduct manufacturing costs by as much as 30% through co-production efficiencies. Besides, high-value markets for bioenergy, biochemicals and biomaterials represent a unique opportunity to extract a maximum value out of the wood fibre and to generate substantial additional economic activity for forest companies. Integrating biorefineries into pulp and paper mills would create additional revenues and diversify their products and markets. Bio-based industries are growing quickly, with sector employment increasing by 13% in Canada from 2006 to 2008. Diversifying markets for forest and agriculture residues increases the value of these materials, providing economic benefits to the residue producers and their local communities.

These new markets are expected to reach a global market potential of $150-$200 billion by 2015. A biorefinery based on a kraft mill may remove part of the hemicellulose and lignin streams that are presently burned in the recovery boiler, and convert them to higher value products such as biobutanol, succinic acid, lactic acid, and lignin-based resins. For a typical kraft mill consuming annually 653,000 oven dry tons of wood chips, a recovery of 36,500 tonnes of lignin from black liquor combined with a 15% increase of pulp production may generate additional annual revenues of 63 M$ from lignin and incremental pulp sales.

Outreach

Build the capacity of industry, engineering community and decision-makers to use a systems approach for implementing solutions that increase plant's efficiency and profitability.

Context

Process Integration (PI) and Data Mining (DM) are powerful tools for improving the design and operation of industrial processes through innovative solutions that save energy, reduce operating costs and emissions, and increase profitability. Over the past decade, a number of successful PI and DM studies have generated typical energy savings of 10 to 30% in both large and medium-sized industries. Yet, even with this early success, results obtained so far represent only a small portion of the potential impact PI and DM can have in the Canadian industrial sector. In fact, these tools are still well underutilized mainly due to limited knowledge of PI and DM benefits as well as insufficient capacity within Canadian engineering firms. This leaves a large potential unexploited, and it is the intent of CanmetENERGY's outreach and capacity building activities to address market barriers for a broader adoption.

CanmetENERGY and its partners have developed a suite of system analysis software packages that include the most recent advancements in our research activities as well as many years of practical experience. These softwares are meant to help Canadian industries improve their process performance and profitability:

INTEGRATION
Uncover heat recovery opportunities and optimize thermal energy use.

COGEN
Maximize revenues from industrial combined heat and power (CHP) systems.

EXPLORE
Use the power of data analysis to improve process operation.

I-BIOREF
Evaluate the technico-economic viability and environmental footprint of biorefinery strategies.

Figure 11: System Analysis Software Packages

Program Strategies

CanmetENERGY's Industrial Systems Optimization Program seeks to build the capacity of industry, engineering communities and decision-makers to use a systems approach for implementing solutions that increase plant efficiency and profitability. This objective is achieved through a market transformation program (**Figure 12**) that provides the information, knowledge, software and support needed to identify, develop, analyze and implement the most cost-effective solutions.

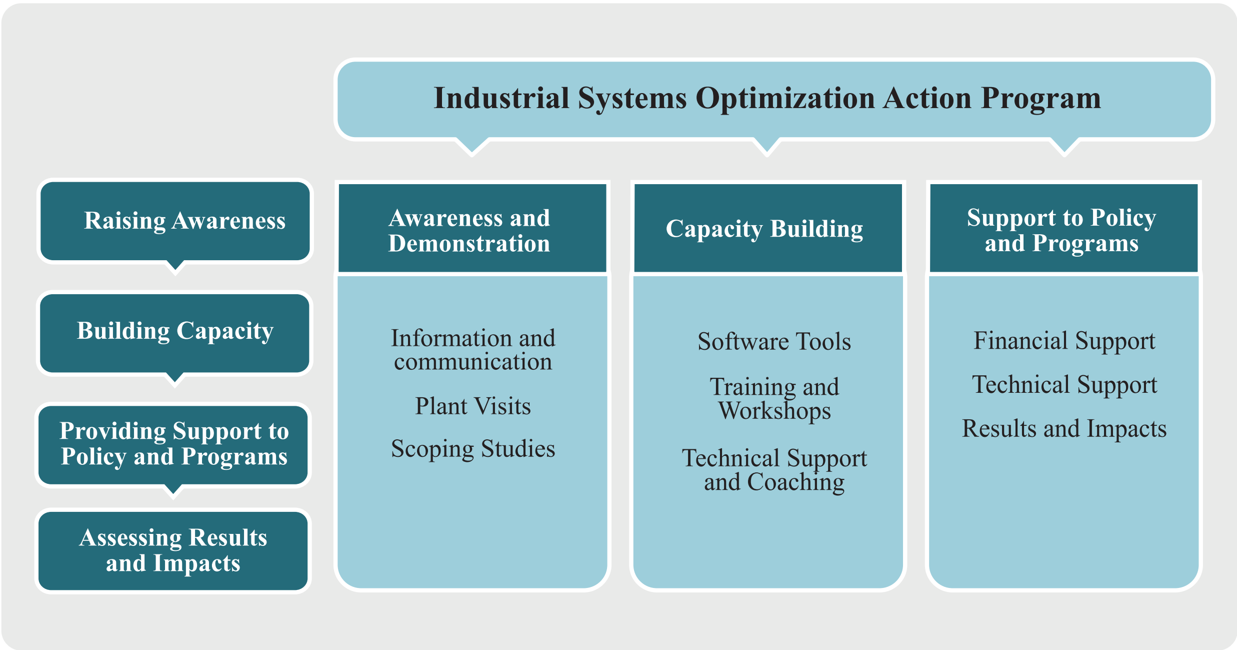

Figure 12: Market Transformation Program – Our Approach

Together, these activities can result in significant energy, financial and environmental benefits for the industry sector and local communities. Moreover, they have the potential to modify the way energy studies are performed in Canada, moving current practices toward more advanced energy assessments based on a systems approach. The knowledge and know-how of professionals will thus increase, which will benefit the entire Canadian industry in the years to come and also well beyond the completion of this program.

Considering the nation-wide scale of this market transformation program, partnering with key stakeholders is essential, notably to provide complementary incentives and logistic support. Partner organizations across the country include federal departments and agencies, provincial departments and agencies, the Canadian Industry Program for Energy Conservation (CIPEC), utility companies, industry associations, and Canadian universities.

Raising Awareness & Communications

One of the key objectives of our outreach and capacity building effort is to raise awareness of the benefits of a systems approach for improving competitiveness in the Canadian industry with a reduced environmental footprint through energy efficiency and new technology integration.

This is done through:

- Explaining the concepts and benefits of our systems analysis tools to decision makers, process engineers and professionals
- Performing customized plant visits, including preliminary on-site analyses, at selected industrial facilities to demonstrate the benefits of a systems approach and how CanmetENERGY's software tools can be applied
- Developing websites to make information (course material, case studies, upcoming events and courses) and software available to the community of professionals, engineering students and decision-makers

Software

To allow effective technology transfer to industry, CanmetENERGY is developing innovative software solutions that include the most recent advancements from our research activities (**Figure 13**).

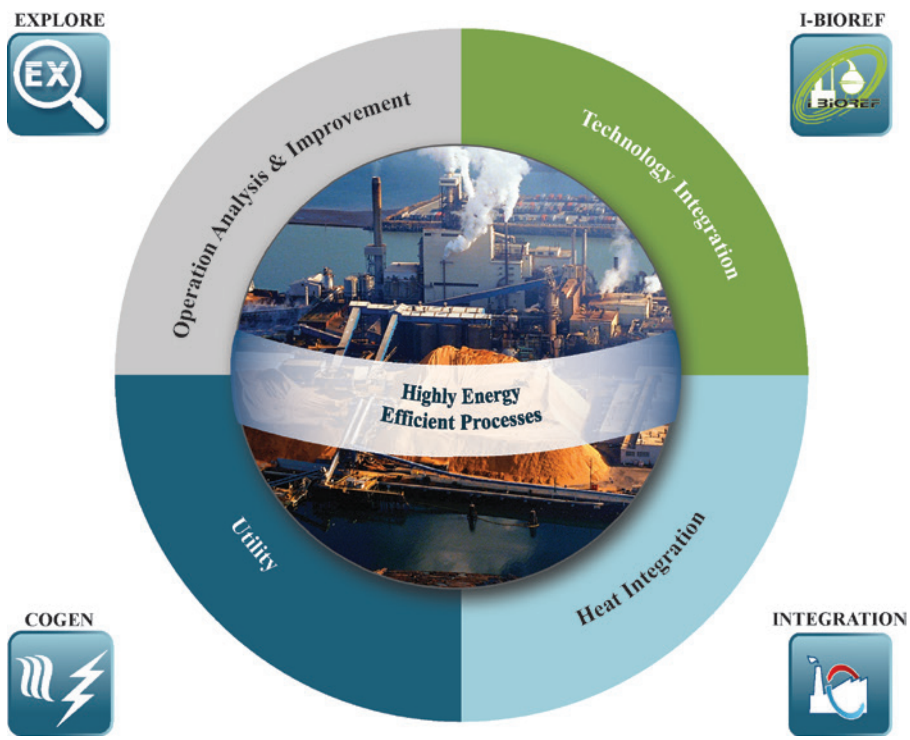

Figure 13: Industrial Systems Optimization Solutions

Our software packages are developed by a team of full-time software professionals working in close collaboration with our researchers and engineers. These state-of-the-art software tools are key enablers to analyze industrial processes and evaluate a range of improvement projects. They are disseminated via a targeted training program to ensure that Canadian engineers and students develop the required skills and that they can properly use them.

INTEGRATION uses a systems approach to optimize heat recovery and reduce thermal energy use in industrial processes. **INTEGRATION** has unique capabilities to quickly identify sources of thermal inefficiency; evaluate operational and design improvement projects to improve the performance of plant's heat exchanger networks and utility systems; assess the viability of various heat recovery, heat pumping and waste-to-energy technologies; and reduce water usage in complex industrial facilities.

COGEN is used to build accurate models and to optimize industrial combined heat and power systems. The complex interactions between steam production, power generation, process steam usage, and condensate return are all analyzed in the same environment. Powerful modeling and optimization capabilities in **COGEN** allow an existing industrial CHP plant to be optimized while taking into account various operational constraints and complex electricity contracts.

EXPLORE uses advanced data analysis techniques to understand and reduce process variability. **EXPLORE** includes several tools to format, pre-process and analyze large and complex data sets; identify the most critical variables affecting process operations; monitor process performance and KPIs; detect, diagnose and fix operational faults in common industrial processes and equipment.

I-BIOREF allows the assessment of the economic viability as well as the energy and environmental impacts of integrating various biorefinery technologies into existing pulp and paper mills. **I-BIOREF** includes capabilities to quickly evaluate the benefits of integrating commercially available processes for pretreatment, lignin, sugar and thermochemical platforms; perform sensitivity analyses on various parameters; analyze the potential for increasing pulp production and yields of biochemicals and biofuels produced; and evaluate environmental impacts using LCA-based metrics.

Training and Technical Support

Since their introduction in 2010, our technical courses have focused on the use of **INTEGRATION** and **EXPLORE**, and they have had a rapid uptake with 200+ engineers trained in 15 sessions. This confirms the need to have technical courses for engineers in industrial facilities and engineering firms in order to improve their knowledge to better analyze, identify, evaluate and implement energy-saving projects. With the continuous enhancement of these software packages, combined with the introduction of new capabilities for optimizing industrial energy systems and the integration of new technologies, it is anticipated that the demand for Process Integration, Cogeneration, Data Mining and Biorefinery courses will grow over the coming years. To meet this growing demand, CanmetENERGY is partnering with other provinces and government organizations to implement a country-wide training and technical support initiative, and also to build a network of qualified trainers to accelerate capacity building across Canada. A range of webinars and training courses that address both the scientific background and the practical use of the software are provided, including:

- Heat integration using Pinch analysis
- Heat recovery and technology analysis upgrading
- Optimization of combined heat and power systems
- Improvement of process operation using Data Mining
- Assessment of biorefinery technologies

As part of the courses, participants are trained to use CanmetENERGY's **INTEGRATION**, **COGEN**, **EXPLORE** and **I-BIOREF** software packages.

To accelerate the learning process and the impact of our training activities, post-training technical support is also offered to workshop attendees to help them perform their first studies using our software. This "mentoring" assistance helps bring these services more rapidly and effectively to industry.

Furthermore, to build long-term capacity, CanmetENERGY is collaborating with Canadian universities to enrich existing courses and build new ones, and to develop the capacity of university trainers to introduce our software into their programs so as to reach the next generation of engineers.

Financial Support and Impact Assessment

Energy efficiency projects generally compete with production projects when plant management decides the budget allocation. Funding is essential to support energy studies but also to facilitate project implementation as demonstrated by the federally-led Pulp and Paper Green Transformation Program (PPGTP), Process Integration (PI) Incentive Program, Investments in Forest Industry Transformation (IFIT) Program and other provincial initiatives. CanmetENERGY can be contacted for more information regarding available incentive programs.

Finally, to measure the effectiveness and efficiency of our outreach and capacity building initiatives, CanmetENERGY is systematically collecting and analyzing industry feedback. This helps to assess changes that can be attributed to our sustained actions and to ensure that the Industrial Systems Optimization Program is producing the intended outcomes in the long run.

Identifying Opportunities, Selecting & Managing Projects

The CanmetENERGY-Varennes Industrial Systems Optimization group is constantly seeking partners interested in collaborating on our research projects and outreach activities. We work closely with industry partners to target priority research areas, conduct demonstration projects and transfer technology and knowledge to various stakeholders and decision-makers.

Multidisciplinary teams, led by project managers, deliver our projects. Every new project is described in a written proposal that is reviewed by the Program Director and project managers, to ensure sound project definition and planning (resource allocation, schedule, clear objectives and deliverables, risk analysis and probability of success). To that end, we employ a disciplined approach to innovation to ensure value for our clients. This approach is based on a set of best practices, called the SRI[16] Five Disciplines of Innovation®, which we use to reliably turn breakthrough ideas into real-world solutions. **Figure 14** describes how we achieve excellence in innovation by effectively managing the innovation chain.

Because having a bright idea is not enough, an innovation occurs only when that great idea is applied to an important customer need and is then delivered to the marketplace.

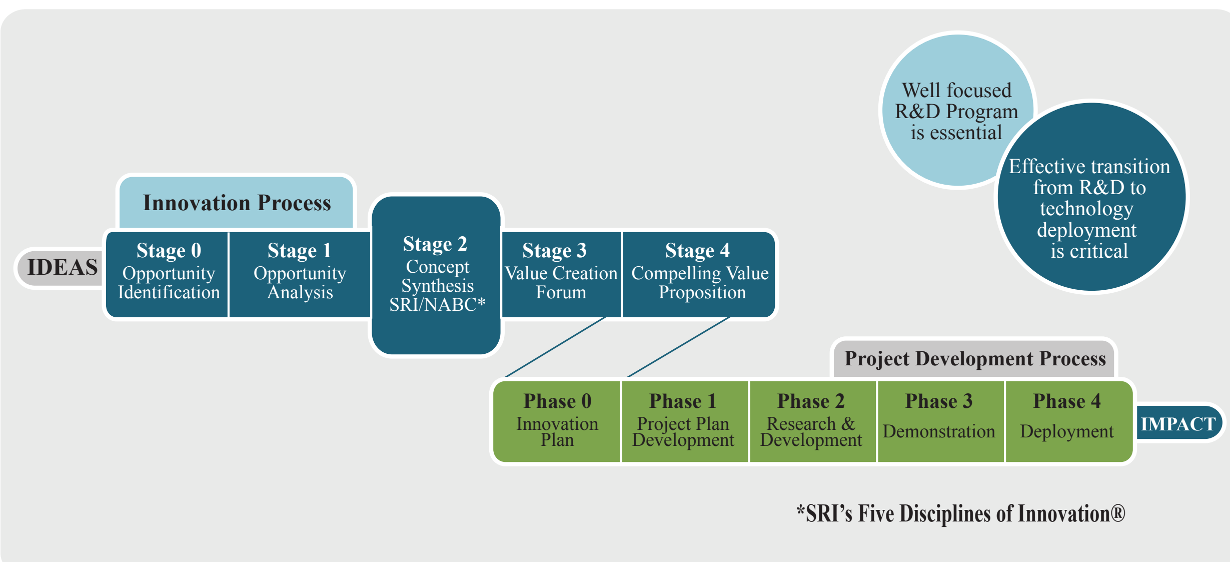

Figure 14: How we Achieve Excellence in Innovation

[16] SRI INTERNATIONAL. "Innovation Programs, SRI's Five Disciplines of Innovation". [Online]. http://www.sri.com/engage/innovation-programs/five-disciplines-innovation

Environmental Scan

Energy is an important component of Canada's industrial sector, which produces (primary) and consumes (secondary) energy. The sector is comprised of numerous establishments, of which the following have over 100 employees[17]: manufacturing (3,505), construction (1,308), mining, and oil & gas (430), agriculture (261), and utilities (126). The diversity of the industrial sector is reflected by many national associations representing its various manufacturing processes.

The industrial sector mainly uses energy for motive power, heating and drying of raw materials, and steam generation. The process energy flows present are, in fact, greater than what would indicate the energy purchase figures, since certain processes also transform a fraction of raw materials into process energy (e.g., petrochemicals, pulp and paper). A part of consumed process energy is also returned to the process for reuse, where possible. Overall, the industrial sector accounts for 30.6% of secondary energy use and 22.1% of secondary energy-related Canadian GHG emissions, thus being the second largest GHG emitter after transportation.

The manufacturing segment includes six large, energy-intensive, single-industry sub-sectors (mining, pulp and paper, iron and steel, smelting and refining, chemicals, and petroleum refining), which consume almost 77% of the total purchased energy.

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[17] STATISTICS CANADA. "Establishments: Canadian Economy (NAICS 11-91)". Canadian Industry Statistics (CIS). [Online]. March 2014. https://www.ic.gc.ca/app/scr/sbms/sbb/cis/establishments.html;jsessionid=00011JFGsP6YVDpwXqSotdL7z4S:-M49BI7?code=11-91&lang=eng

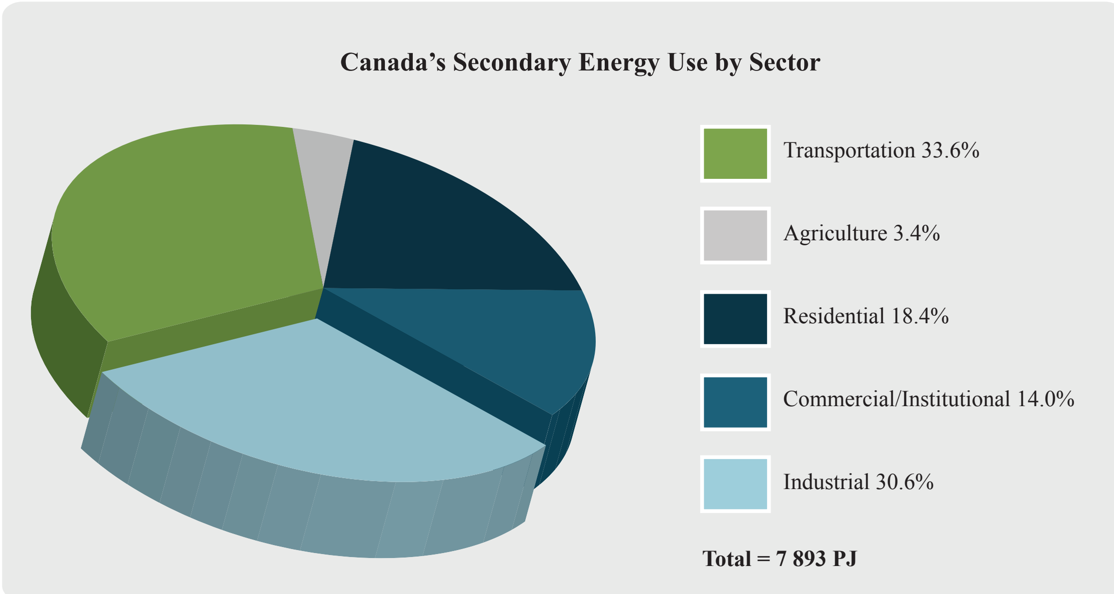

Figure 15: Canada's Secondary Energy Use by Sector

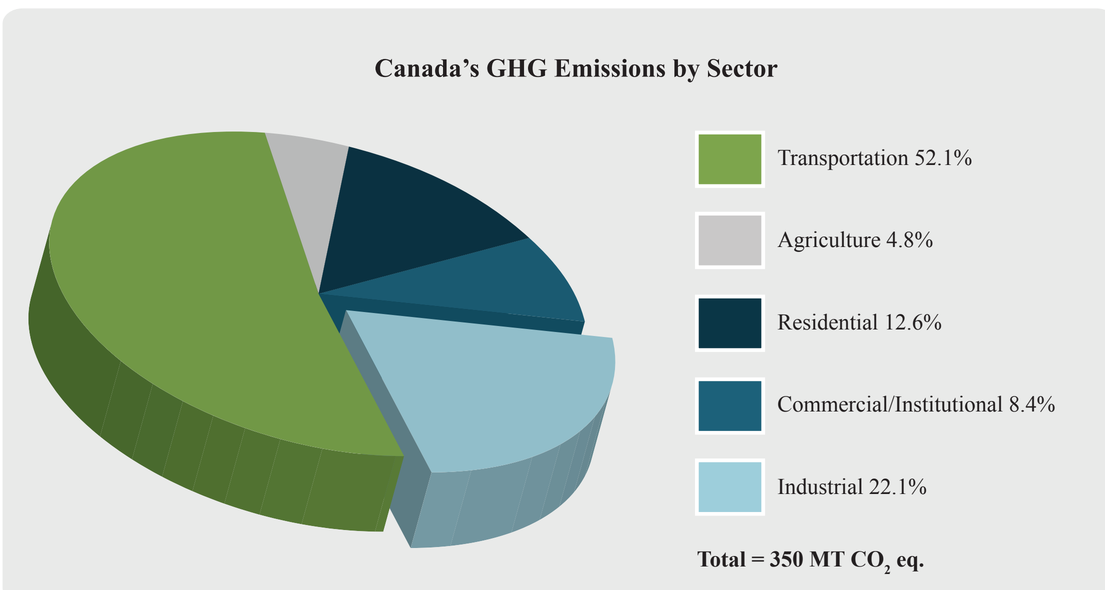

Figure 16: Canada's GHG Emissions by Sector

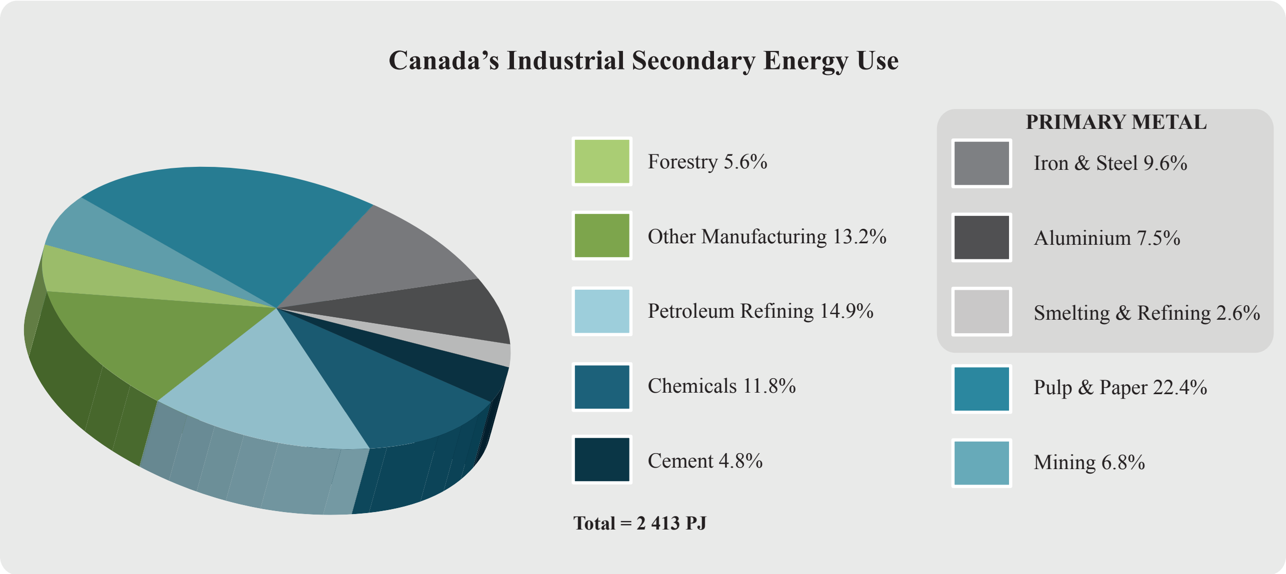

Figure 17: Canada's Industrial Secondary Energy Use

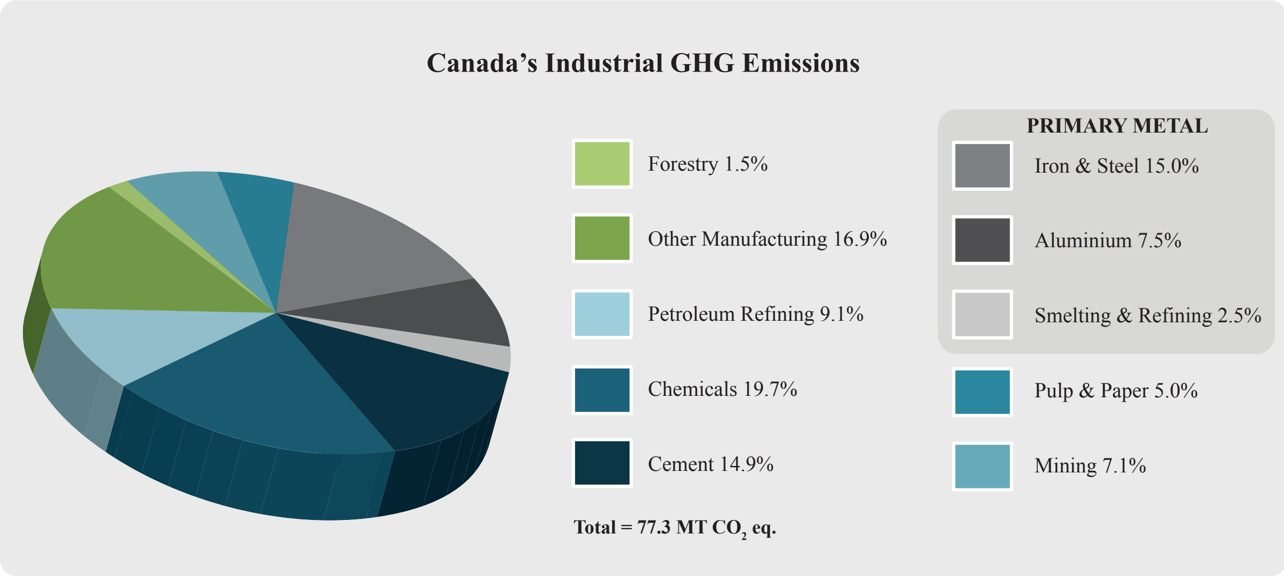

Figure 18: Canada's Industrial GHG Emissions

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