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Comparative Economics of Combined Cycle, Solar, Wind, Hydro, and Geothermal Power

University of Calgary, Haskayne School of Business, Calgary, Alberta, Canada, October 19, 2017

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Gas, Oil and Renewables

- Regulators and Policy Makers and government agencies (e.g., Mexican, US governments)
- Power Producers such as Vattenfall and Iberdrola
- National Oil & Gas Companies such as Saudi Aramco, PDVSA, CNPC, and Gazprom
- International Oil & Gas Companies such as BP, Total, Novatek, and American Energy
- Lenders such as The World Bank and USAID
- Suppliers such as Siemens (motors), BASF (chemicals), and Wood Group (turbines)
- Law Firms such as Duane Morris LLP and Kirkland & Ellis LLP

Adapting to Change

- Market opening, reform or deregulation requires elevated procurement capability
- New stringent technical requirements require evaluation of alternative technologies
- Major capital projects failing to meet target rate of return
- Diversification into a related business with different supply market dynamics

Strategic Planning

- Strategic Planning
- Economic and Fiscal Impact Studies
- Value Chain Planning
- Cost Reduction Projects
- Training & Organizational Development
- Data Security in the Supply Chain

"50x" Payback

- 20-30% profit margin improvement
- 50% cycle time compression
- 50+ times payback on consulting services

Proven Track Record

- Founded in 1998
- Offices in USA, Mexico, Colombia, UAE, Bahrain, Saudi Arabia, and India

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Energy Industry Value Chain Optimization

Pre-Feasibility | *FEED* | *FID* | *Tendering* | *Construction*

Custom Market Analytics for Engineered Products and Services

A market intelligence solution that saves buyers money and helps them avoid costly mistakes by recommending timely procurement actions and technology strategies.

- MarketOutlook.com
- Supply risk mitigation model
- Supplier Optimization Model

Organization Design and Development

Training and development workshops and programs.

Operations Improvement

- Process and equipment standardization
- Vendor managed inventory
- Sales & operations planning
- Demand planning
- Debottlenecking
- Preventive maintenance
- Capital spares management

Service

Independent Cost Benchmarking | Value Chain Engineering | Tender Design & Management | Supply Contract Negotiation | Project Controls | Claim Drafting and Rebuttal

Purpose	• Benchmark Project Economics	• Determine Ways to Achieve Target Economics	• Manage EPCI Activities • Ensure Capacity Availability, Price Stability	• Minimize Budget Variances	• Control in project execution • Objective claim drafting & rebuttal
Projects	• Capital Project Cost Estimates • Equipment / Component Cost Estimates	• Supply Chain Strategy (for Buyers) • Value Chain Strategy (for Suppliers)	• Supplier Prequalification • Technology Selection • Preparation of Invitations to Bid	• Negotiation Support • Hands-on Negotiation	• Out of pocket costs • Damages
Savings					

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Serving Industry Majors

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Europe has been mandating clean energy since 1998

Clean Energy Milestones in Europe

EU

- 2005: Emission Trading System (ETS) includes all large CO_2 emitters – power plants, large industrial installations and platforms for oil and gas production. 2007 resolution mandating 20% renewable energy by 2020
- 2012: CO_2 emissions from aviation are included in the EU ETS

UK

- 2001: Climate Change Levy on natural gas, electricity, petroleum and liquid gas, coal, lignite and coke
- 2008: Climate Change Act: conditional target to reduce emissions by 50% by 2027 on condition that EU adopts common reduction targets post 2020.
- 2008: Target 34% cut in greenhouse gas emissions by 34% by 2020

Denmark

- 1992: Carbon tax covers all consumption of fossil fuels (natural gas, oil, and coal)
- 2012: Energy Agreement: 35% of energy from renewable sources, 12% cut in energy consumption vs. 2006, and 50% of electricity from wind
- 2013: Target cut in GHG emissions by 40% by 2020 vs. 1990 level
- 2013: Oil for heating, and coal, to be phased out by 2030

Others

- 2001 German decision to phase out nuclear energy by 2020
- 2012: Bulgaria, France, and the Netherlands ban on fracking
- Denmark, Lithuania, and UK set permitting and approval procedures for use of chemicals; establish monitoring and reporting procedures

Source: Jacoby, D. *High Cost of Low Prices: A Roadmap to Sustainable Prosperity*, Business Expert Press, 2017.

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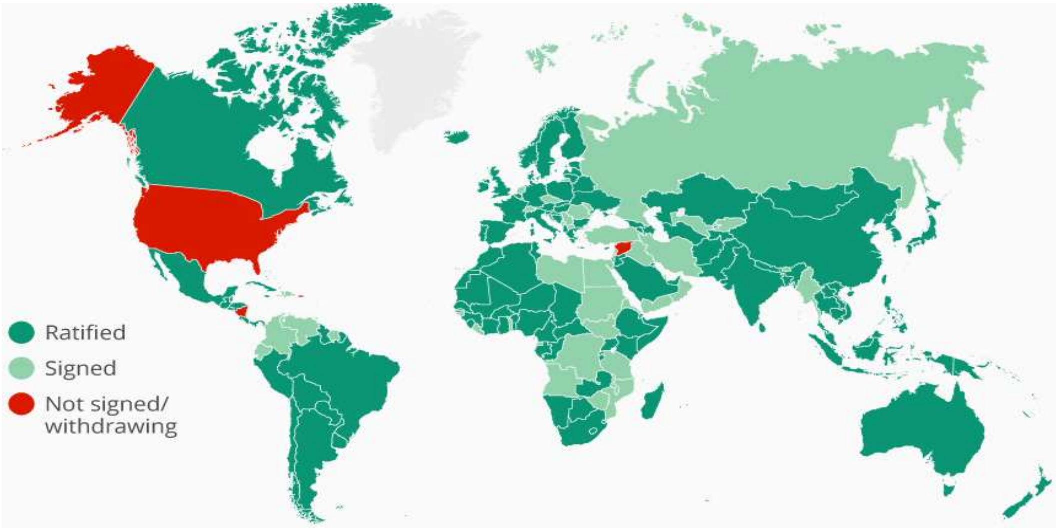
195 countries have signed the Paris Accord, and 167 have ratified it

Guidelines / country commitments of the Paris Accord

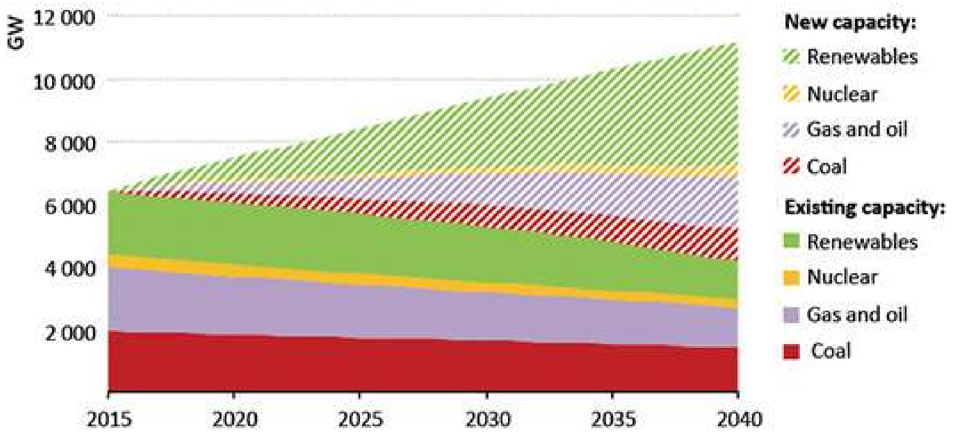
- Mitigating emissions
  - Limiting global average temperature increase to **below 2°C above pre-industrial levels;**
  - Limit temperature increase to below **1.5°C** from current levels to significantly reduce risks and impacts of climate change;
  - Reduce **global emissions to peak as soon as possible**, recognizing it will take longer for developing countries;
  - Achieving **rapid reductions thereafter** per best available science.
  - Develop **national climate action plans.**
- Establishing accountabilities
  - **Set more ambitious targets** every 5 years as per science;
  - **Report** how well we are doing to implement the INDCs;
  - Track progress towards the long-term goal through a robust **transparency and accountability** system
- Facilitating adaptation
  - Strengthen ability to **deal with the impacts** of climate change;
  - Provide continued and enhanced international **support** for adaptation **to developing countries**.
- Coping with loss and damage
  - Recognize the importance of averting, minimizing and addressing **loss and damage** from climate change;
  - Jointly establish **early warning systems, emergency preparedness and risk insurance**.

Membership of Paris accord



Source: UNFCCC, *Business Insider*

Implications for clean energy



Source: IEA. *World Energy Outlook 2016*

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Regulatory mandates elsewhere are influencing the rate of adoption of renewables

Key axes of regulatory action

Indicator	Current Global Average	Potential 2030 Global Average
Carbon Tax Rate on Energy Production	1.5%/bbl, 3%/MMBtu global average (18%/bbl, 37%/MMBtu for 15 countries with carbon taxes)	18%/bbl, 18%/MMBtu
Maximum Air Pollution Standards	Actual: 58 ug/m3, PM10=85 Standards: 20-50 ug/m3	28-29 ug/m3 PM10=77
Mandated Low-Carbon Fuel Standards	34 countries with mandates average 7% content of alternative fuel/renewable energy in transport	50 countries with an average of 10-20% of alternative fuel/renewable energy in transport by 2020

Source: Jacoby, D. *High Cost of Low Prices: A Roadmap to Sustainable Prosperity*, Business Expert Press, 2017.
Note: Greenhouse Gas Emissions per Capita projected to decrease from 6.4 tonnes to 5.9 tonnes between 2017 and 2030.

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Low-cost Asian manufacturing has also been driving down cost, making renewables more cost-competitive

Solar

- Prices of solar PV modules down 47% 2010-2015.
- Polysilicon costs fell 62%.
- Cost of solar PV module installation down 58%
- Cost of invertors down 13%
- Balance of System (BOS) steady.

Wind

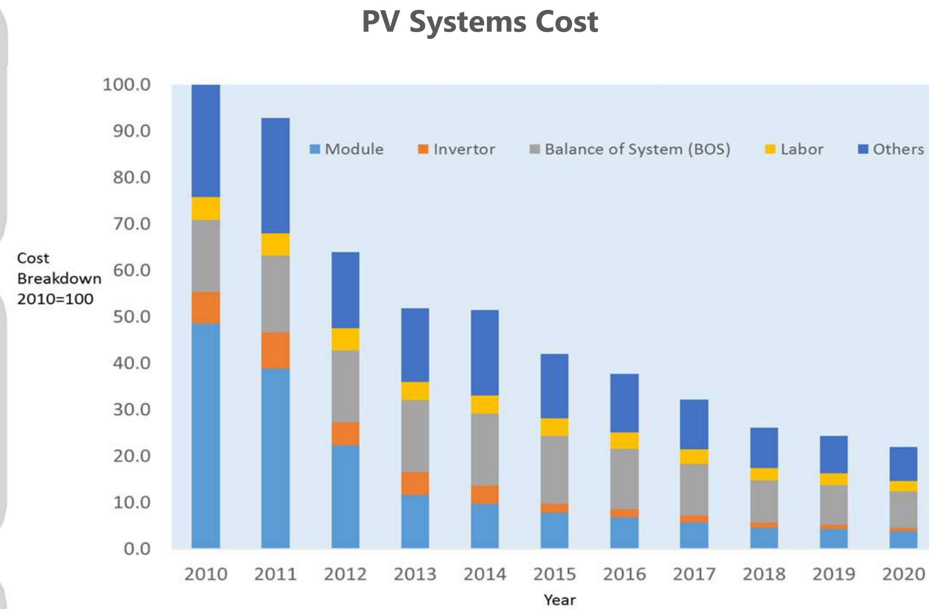
- Wind turbine (including towers and installation) 64%-84% of total installed costs.
- Wind turbine prices down 30-40% 2009 to 2015.

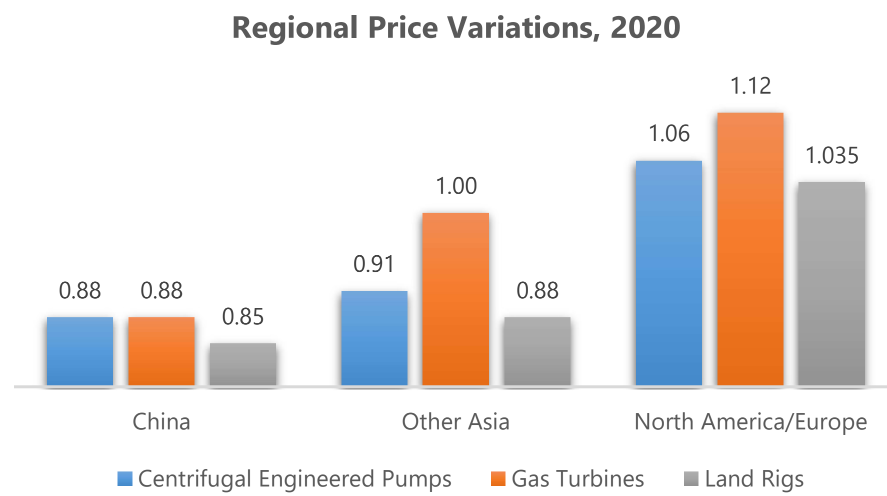
Geothermal

- Global total installed cost fell 6% 2010-2014 ($1,900-$5,500/kW fell to $1,850-$5,100).
- Power plant: 42% of Total Installed Costs.
- Production, injection, and test wells: 20%.
- Steam field development: 14%.

Hydro

- Mature technology, with limited cost reduction potential in most settings.
- Total installed costs steady $450-3,500/kW 2010-2014.
- Civil works and equipment costs: 75-90% of total investment cost





Source: *Photovoltaic Systems Market report, 2016.

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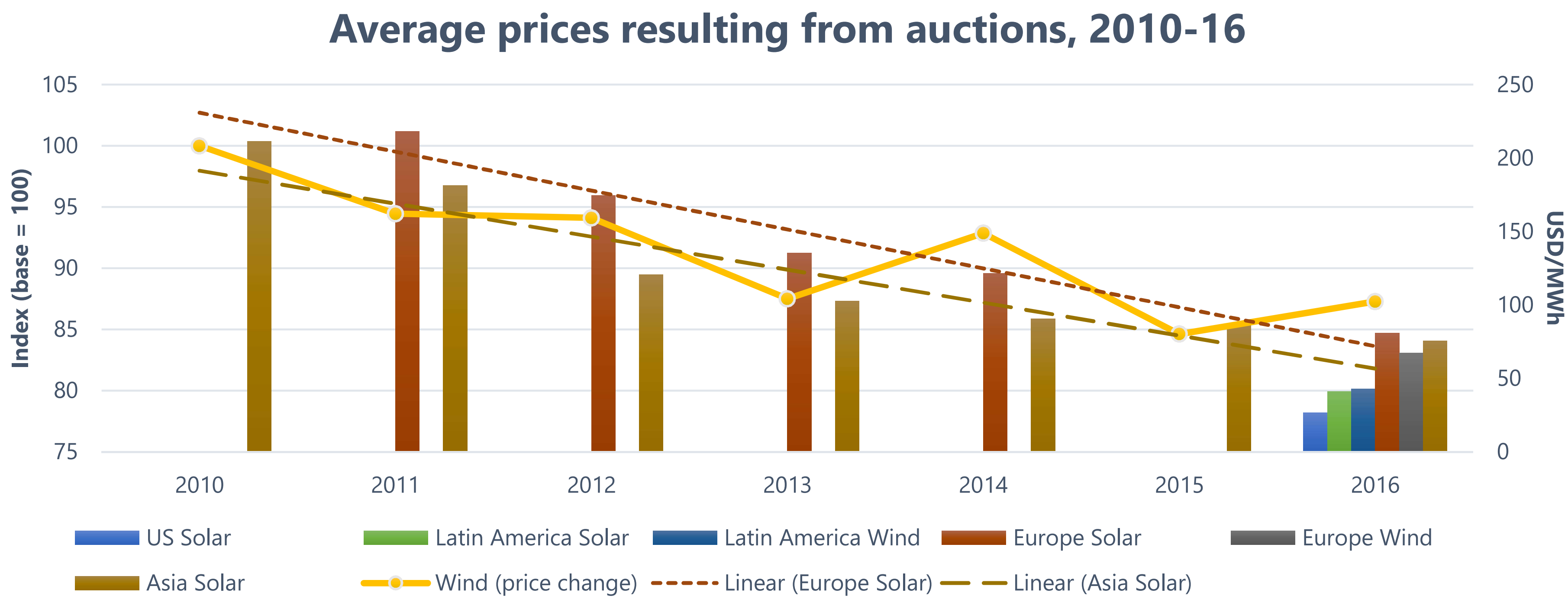
Prices for solar and wind energy have fallen, especially since 2010



- The potential of auctions to achieve low prices has been a major motivation for their adoption worldwide.
- In 2010, solar energy was contracted at a global average price of almost USD 250/MWh, compared with the average price of USD 50/MWh in 2016. Wind prices have also fallen, albeit at a slower pace, as the technology was more mature in 2010.
- Historical chart data for Solar is constructed based on proxies and indices of Asian PV manufacturing costs and European O&M costs

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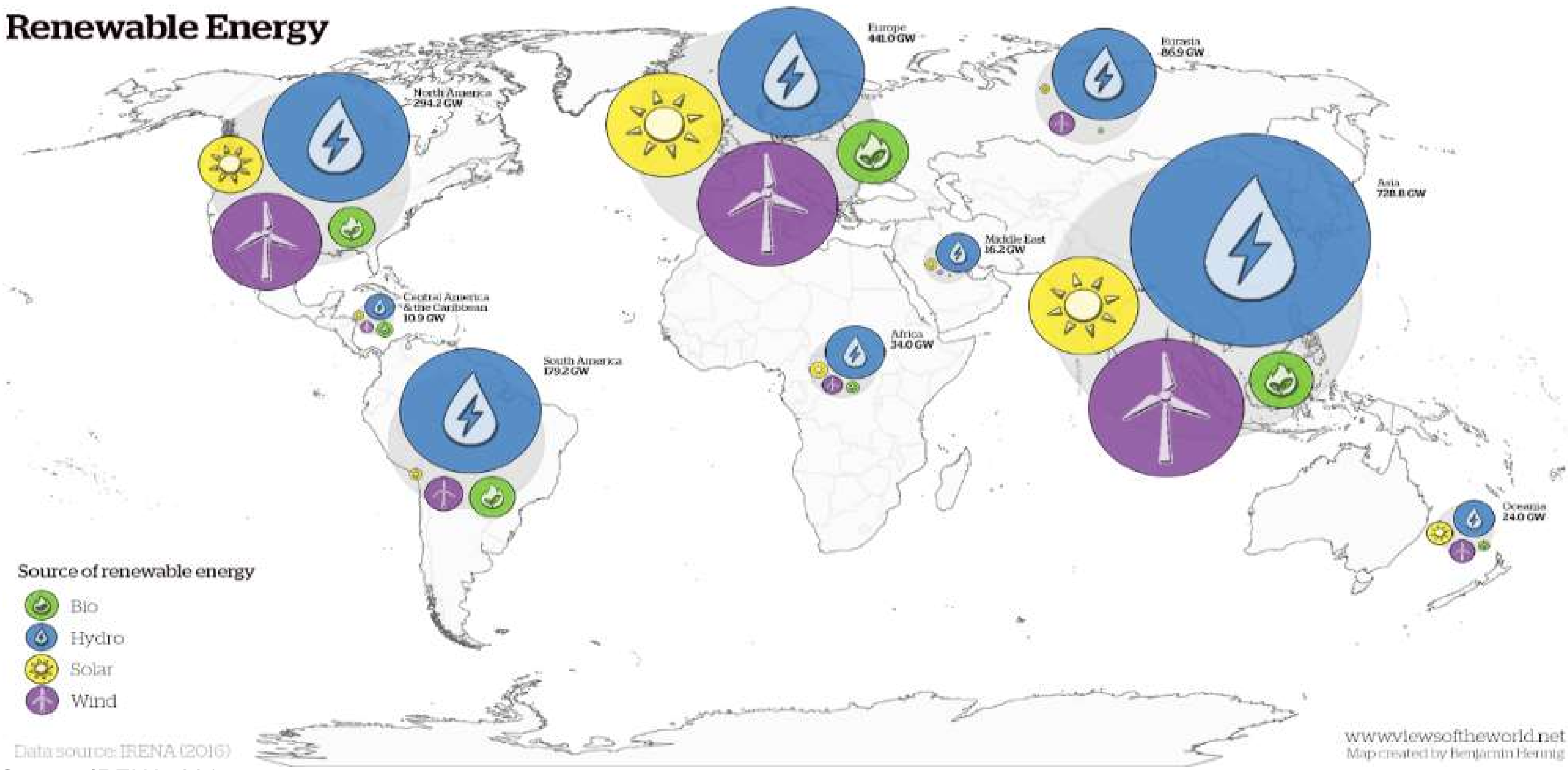
Globally, renewable capacity largely consists of hydro, wind and solar

Asia tops renewable capacity (40.1% of world total), followed by Europe (25%), North America (16.6%), South America (9.1%), and Eurasia (including Russia, the Caucasus, and Turkey, 4.5%).

Global overview of the installed renewable energy capacity across main regions in 2015



Source: IRENA, 2015.

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Over 80% of Canada's renewable energy consists of hydropower

Installed capacity by renewable energy technology in Canada

Hydropower: 83.4%

542 hydroelectric stations: 78 GW of installed capacity, including 379 small hydroelectric facilities of 50 megawatts or less, which together represent 3.6 GW (4.6% of Canada's installed capacity).

Installation	Capacity (MW)	Province
Centrale Robert-Bourassa	7,722	Quebec
Churchill Falls	5,428	Newfoundland and Labrador
La Grande-2A, -3 and -4	2,106 MW for 2A, 2,417 MW for 3 2,779 MW for 4	Quebec

Wind: 11.8%

Installation	MW	Province
Blackspring Ridge	300	Alberta
Seigneurie de Beaupré 2/3	272	Quebec
Gross-Morne Wind Farm	212	Quebec

Total installed capacity: 9.7 GW. 5,130 wind turbines operating on 225 wind farms, vs. 60 wind turbines, 8 wind farms and 27 megawatts in 1998.

Solar: 2.6%

Installation	MW	Province
Grand Renewable Solar Project	102	Ontario
Sarnia PV Power Plant	97	Ontario

10th largest annual PV installations worldwide. Added 600 MW of PV capacity.

Source: IRENA, NRCAN
Note: The remaining percentage of renewable energy is related to bioenergy.

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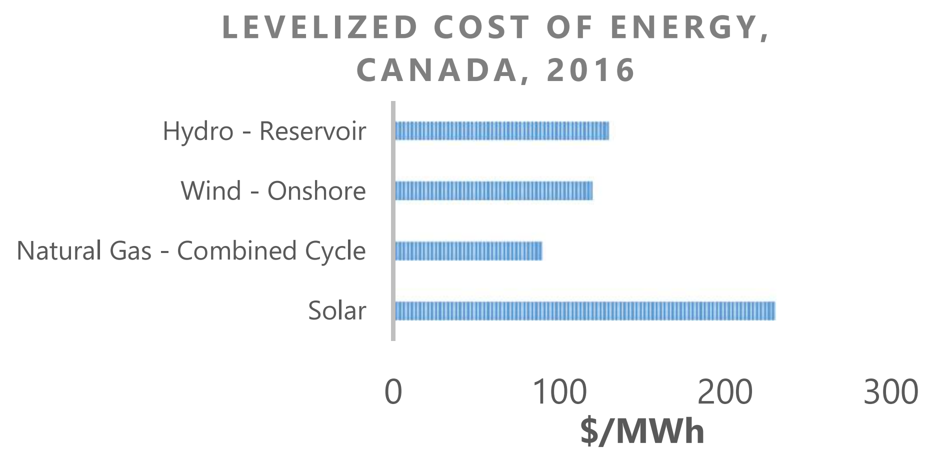
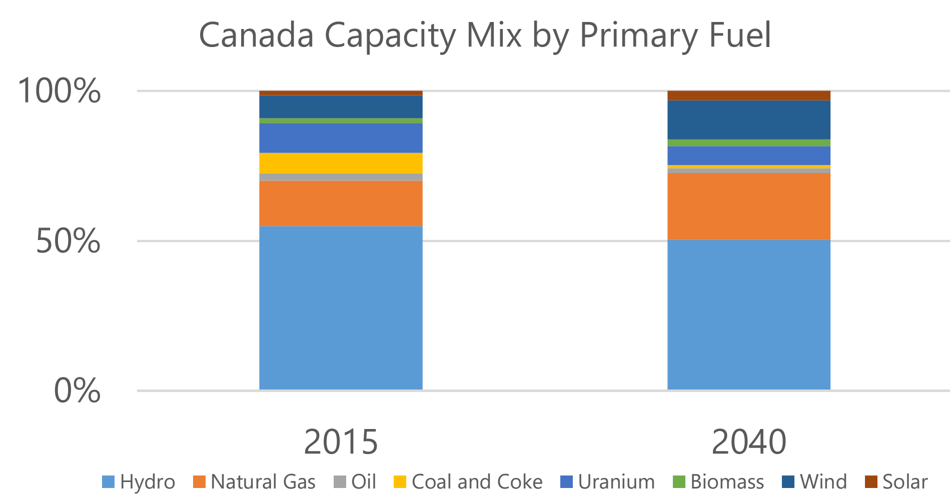
As a result of regulatory and economic trends, natural gas will increasingly compete with renewables

- Natural gas elevated by cheap E&P costs and tightening emissions standards.
  - Historically low prices (lowest since 1998)
  - Up to 50% lower CO2 emissions
- Coal being marginalized by tightening air emissions standards
  - Coal-fired power plants commissioned before 2016 emit 100-150 ug/m3 of PM in Asia, while existing coal-fired power plants in Germany and USA emit 20 and 18.5 ug/m3 respectively. EU 2030 target is 29 ug/m3.
  - China shifting away from its reliance on coal, which accounted for 65% of its energy in 2015. In 2016 China decided to stop building 103 coal-powered power plants that were in construction or planning phases.
- Oil threatened by electric vehicles
  - Professor Tony Seba of Stanford University
    - No more driving
    - No more car ownership
    - "Computers on wheels" (software-driven)
    - 200+ mile range at $20,000 cost
    - China: 7 million electric vehicles by 2025
  - "All fossil-fuel vehicles will vanish in 8 years in twin 'death spiral' for big oil and big auto"



Source: National Energy Board Canada



Source: Canada´s Energy Future 2016

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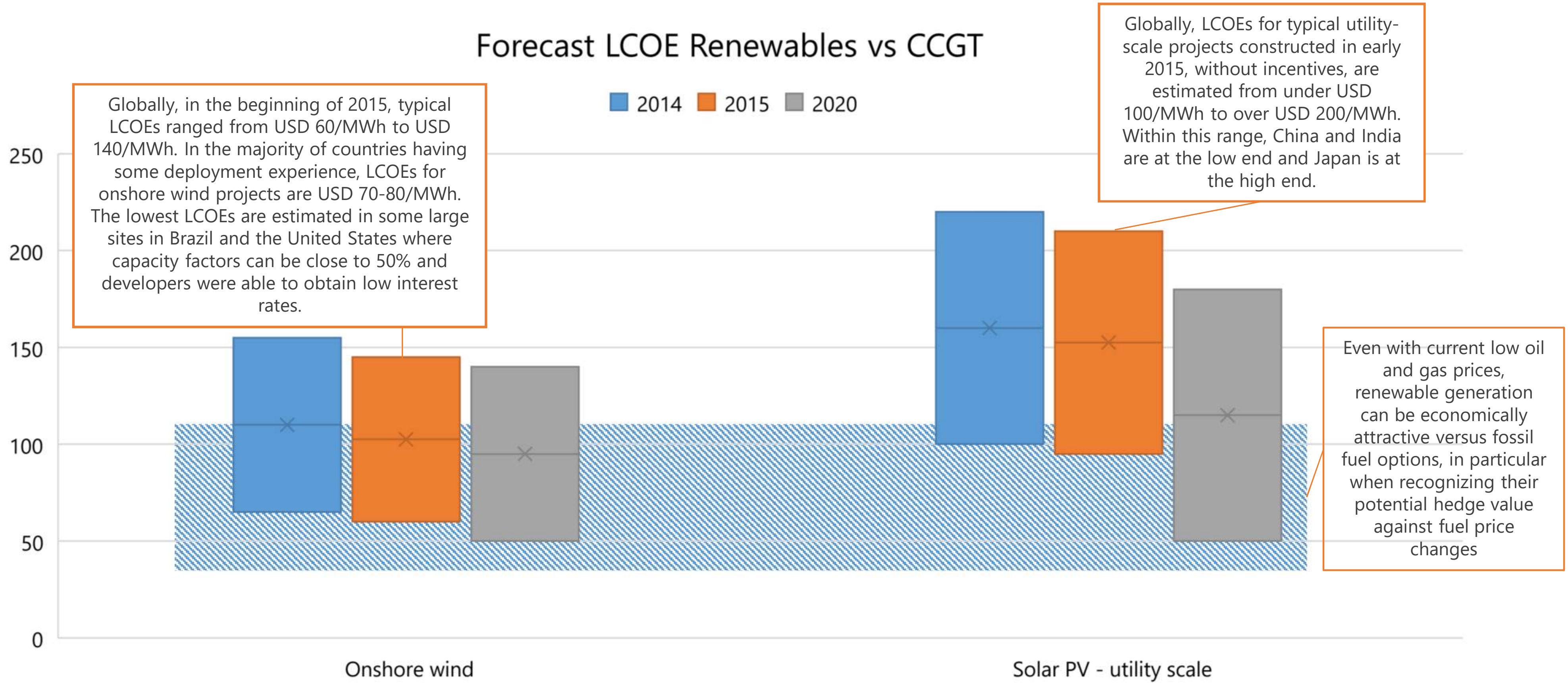
The economics of renewables will compete with conventional power



Notes: Costs are indicative and ranges reflect the system cost, resource and financing differences among countries.
Source: Analysis BSI. [INECC, Value Chain Study of Four Different Power Generation Technologies.]

- Main drivers of the cost-competitiveness of renewable options: Technology progress, expansion into newer markets with better resources, and better financing conditions, often supported by market frameworks based on price competition for long-term PPAs
- As a result, the estimated global weighted average levelised cost of electricity (LCOE), without incentives, for some renewable sources has shown strong reductions over time, with further decreases forecast.

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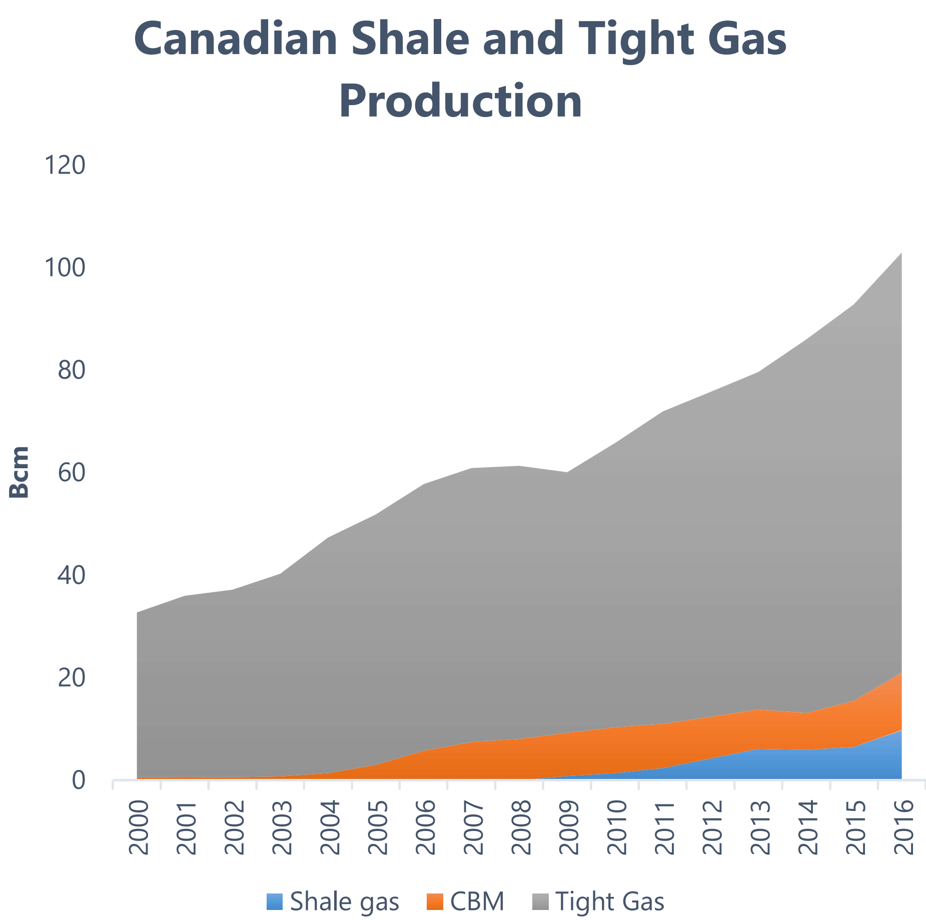
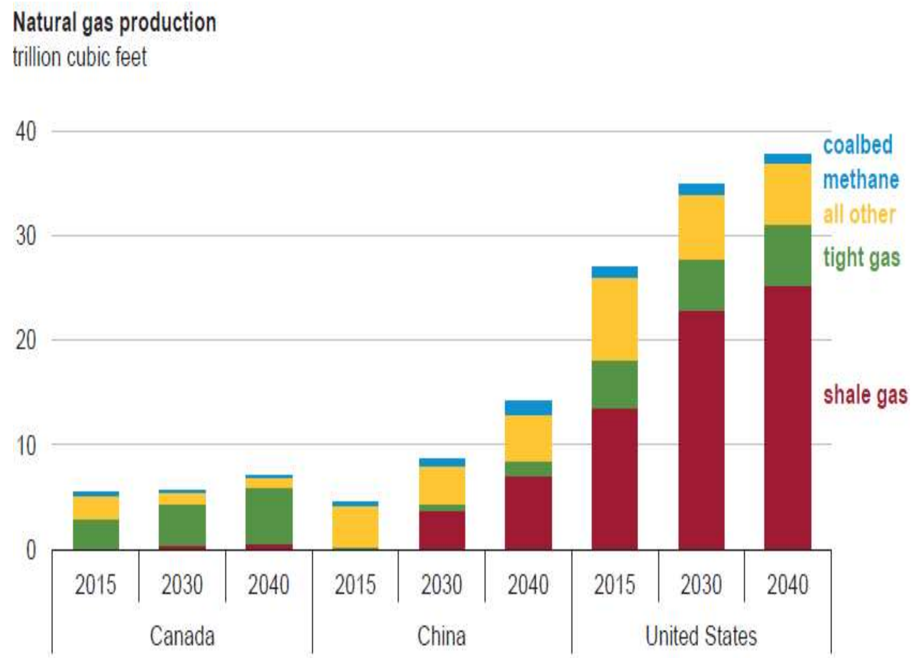
However, Canada is rich in non-renewable resources, which will affect the rate of adoption of renewables.



Source: IEA

Shale and tight resources become increasingly important to natural gas supplies

- In Canada, future natural gas production is expected to come mainly from tight resources, from British Columbia and Alberta.



Source: EIA, International Energy Outlook 2017

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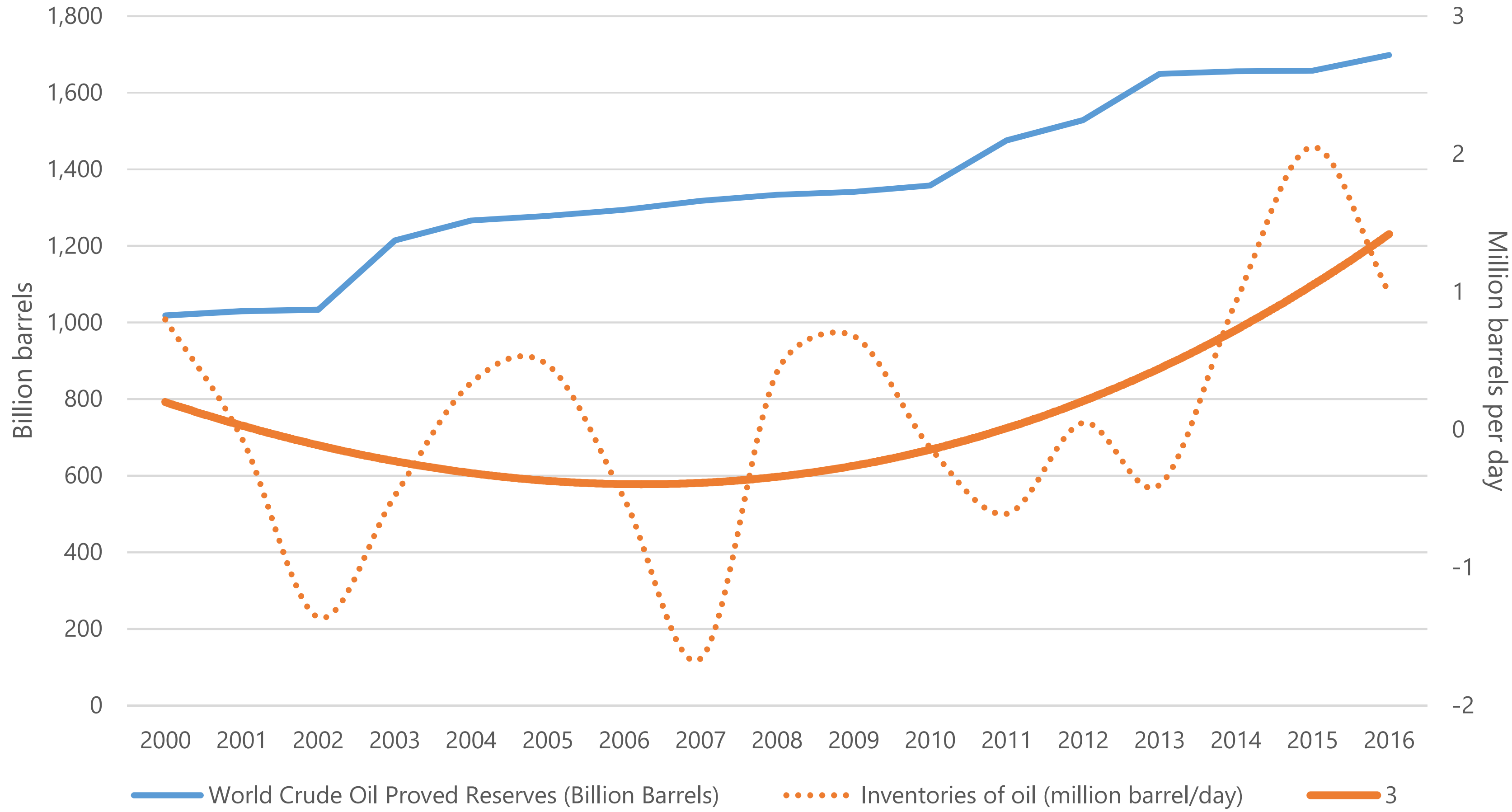
Upstream technological advances are enabling historically low-cost natural oil and gas



Oil reserves have increased

- World crude oil proved reserves increased 63% from 2000 to 2015.
- Inventories rose 150% between 2000 and 2014.
- Global benchmark Brent crude price has fallen from $111.80 per barrel in June 2014 to $30 per barrel in January 2016, curtailing upstream oil & gas development.

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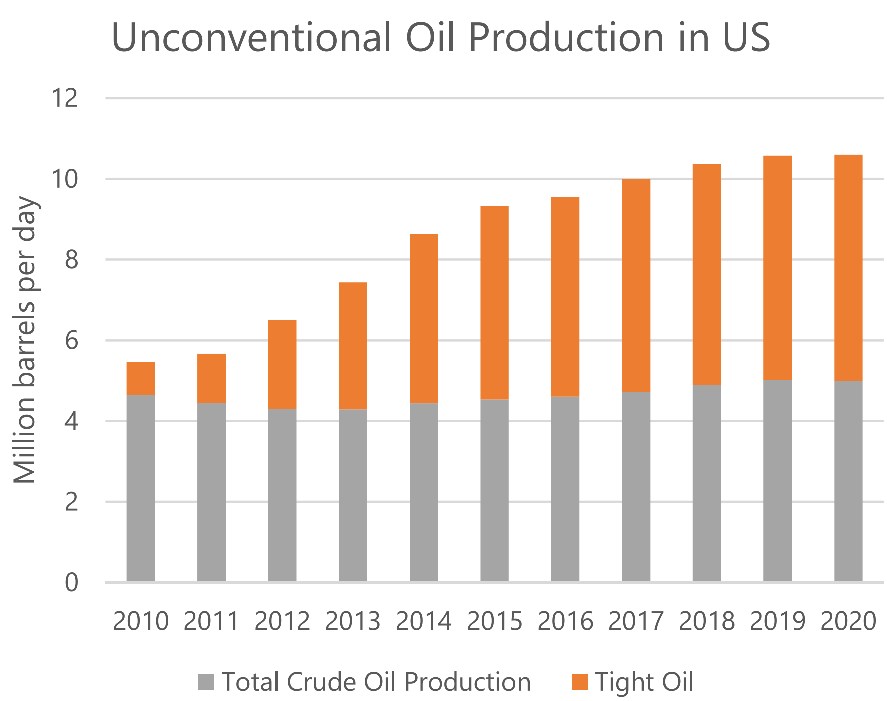
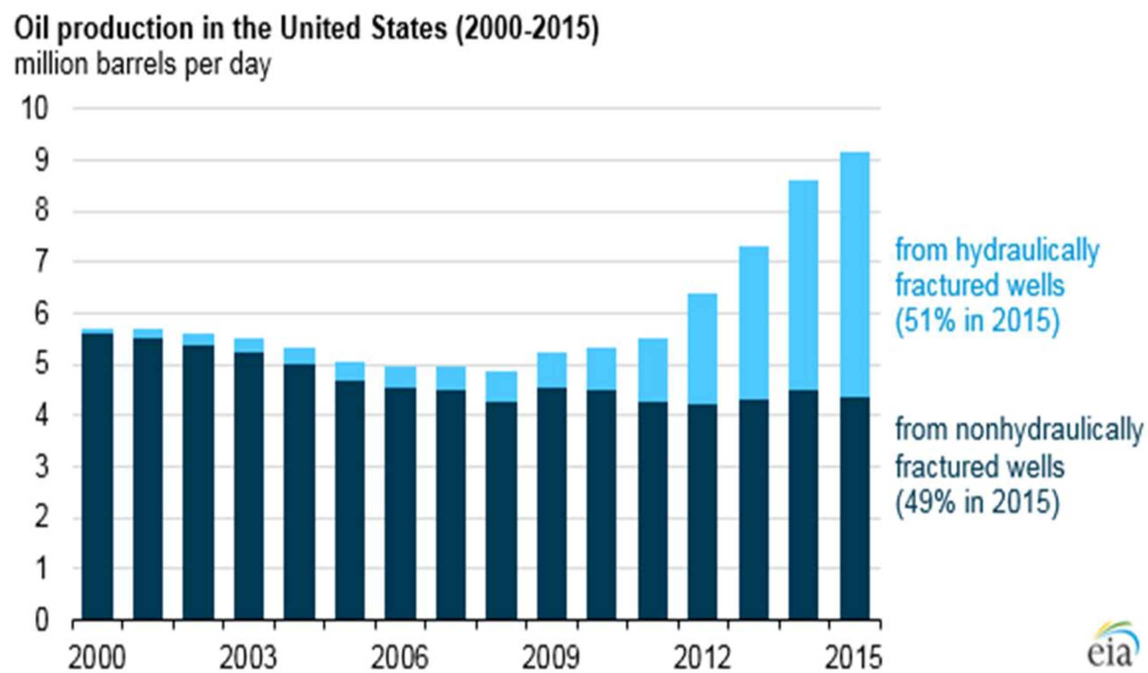
Directional drilling, hydraulic fracturing and other unconventional techniques are “the new normal”





Production from tight formations increased from 0.5 million b/d in 2009 to 4.6 million b/d in 2015, 50% of total U.S. oil production.

Hydraulic fracturing, often used in combination with horizontal drilling, has allowed the United States to increase its oil production faster than at any time in its history.

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Midstream, a bevy of technologies is helping to reduce cost and improve safety

- UAVs
- Radar/LIDAR
- Intrusion Detection via Image Pattern Recognition
- Infrared Imaging
- Smart Pigging
- Magnetic Flux Leakage
- Ultrasonic Tools
- Geometry Tools
- Distributed Fiber Optic Sensing
- Acoustic Sensors
- Temperature and Strain Sensing
- Electric Field Mapping
- Pipe Coating, Lining and Cathodic Protection
- Cyber-Secure Networks

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In-Line Inspection (ILI): "Smart Pigging"

- Advances in magnetic-based In-Line Inspection (ILI) technology have enabled pipeline operators to reduce corrosion as a cause of pipeline incidents by nearly 80% over the last 15 years.
- Several crack-focused ILI technologies are performing well.
- ILI technology providers and operators are currently harnessing ultrasound, combinations of magnetic and ultrasound, and advanced computer analytic techniques to find and diagnose potential cracks in pipelines.
- Various types of smart pigging are discussed in the following slides:
  - Magnetic Flux Leakage (MFL)
  - Transverse MFL / TFI
  - Ultrasonic Tools
  - Geometric Tools

Source: aopl.org

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Magnetic Flux Leakage (MFL)

- Electronic tool that identifies and measures metal loss (corrosion, gouges, etc.) through the use of a temporarily applied magnetic field. As it passes through the pipe this tool induces a magnetic flux into the pipe wall between the north and south magnetic poles of onboard magnets.
- A homogeneous steel wall – one without defects – creates a homogeneous distribution of magnetic flux. Anomalies (i.e., metal loss (or gain) associated with the steel wall) result in a change in distribution of the magnetic flux,which, in a magnetically saturated pipe wall, leaks out of the pipe wall.
- Sensors onboard the tool detect and measure the amount and distribution of the flux leakage. The flux leakage signals are processed, and resulting data is stored onboard the MFL tool for later analysis and reporting.

Source : primis.phmsa.dot.gov

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Transverse Flux Inspection (TFI)

- Identifies and measures metal loss through the use of a temporarily applied magnetic field that is oriented circumferentially, wrapping completely around the circumference of the pipe.
- It uses the same principal as other MFL tools except that the orientation of the magnetic field is different (turned 90 degrees).
- The TFI tool is used to determine the location and extent of longitudinally-oriented corrosion. This makes TFI useful for detecting seam-related corrosion.
- Cracks and other defects can be detected also, though not with the same level of reliability.
- A TFI tool may be able to detect axial pipe wall defects – such as cracks, lack of fusion in the longitudinal weld seam, and stress corrosion cracking – that are not detectable with conventional MFL and ultrasonic tools.

Reference : primis.phmsa.dot.gov

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Ultrasonic Tools

- Compression Wave Ultrasonic Testing (UT) : measure pipe wall thickness and metal loss. These tools are equipped with transducers that emit ultrasonic signals perpendicular to the surface of the pipe. An echo is received from both the internal and external surfaces of the pipe and, by timing these return signals and comparing them to the speed of ultrasound in pipe steel, the wall thickness can be determined. This is especially important for crude oil lines.
- Shear Wave Ultrasonic Testing (also known as Circumferential Ultrasonic Testing, or CUT) is the nondestructive examination technique that most reliably detects longitudinal cracks, longitudinal weld defects, and cracklike defects (such as stress corrosion cracking). It uses shear waves generated in the pipe wall by the angular transmission of UT pulses through a liquid coupling medium (oil, water, etc.).

Source : primis.phmsa.dot.gov

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Geometry Tools

- Geometry tools use mechanical arms or electromechanical means to measure the bore of pipe. In doing so, it identifies dents, deformations, and other shape changes.
- It can also sense changes in girth welds and wall thickness. In some cases, these tools can also detect bends in pipelines.
- The remediation criteria depend on both the depth and orientation of dents, so geometry tools that are used to detect deformation anomalies such as dents, should provide both the orientation, location and depth measurement of each dent.
- This tool can be used for hazardous liquids and natural gas pipelines.

Source : primis.phmsa.dot.gov

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Distributed Fibre Optic Sensing

- Distributed optical fibre sensors offer the capability of measuring at thousands of points simultaneously, using a simple, unmodified optical fibre as the sensing elements.
- Resistive strain gages are the most common sensor type and are composed of a zigzag pattern of copper foil that is calibrated to produce voltage changes proportional to the pattern's geometric expansion due to being glued onto the underlying material.
- Once the gauges have been attached and the lead wires have been bundled and routed, all of the signals must be connected to a centralized data collection system with an array of channels. With individual calibration constants, the sensing channel for each gauge must be adjusted in order to accurately measure strain, resulting in bundles of electrical wires that are running along the structure, occupying space and requiring regular maintenance to ensure that they really work.
- There 2 main types of DFOS systems currently in use in Oil & Gas for Pipeline Safety-
  - Distributed Acoustic Sensing (DAS)
  - Distributed Temperature & Strain Sensing (DTSS)

Source: ctemps.org

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Acoustic Sensor for Leakage detection

Figure 8: UTCD/UTWM Ultrasonic Tool

Figure 11: Weatherford's latest generation of Ultrasonic sensors

Source: Weatherford

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Distributed Temperature and Strain Sensing (DTSS)

- DTSS are sophisticated sensor systems using Brillouin scattering in optical fibers to measure changes in both temperature and strain along the length of an optical fibre.
- By wrapping or embedding a fibre inside a structure, such as an oil pipeline or dam, one can detect when the structure is being strained or heated/cooled, and correct the problem before failure occurs. The sensing technology gives both strain and temperature readings along the length of the fibre, with spatial resolution as short as 10 cm.
- Depending on the configuration selected, measurements can be made over the entire length of fibre, up to 100 km in length. One can use such a setup to monitor a very long length device, like a pipeline or highway, or lay the fibre to form a 2D or 3D grid in a structure, like a dam wall or submarine hull.
- Measurements can be made up to the entire length of fibre (Typically 100km)

Source : ozoptics.com

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Electric Field Mapping (EFM) for Corrosion Monitoring

- The system uses an array of electrodes to measure localized differential voltages and map the electrical field generated by a controlled current. Changes in resistance occur from variations in both metal thickness and temperature.
- Temperature variations normally occur with ambient and process condition changes. The PinPoint Electrical Field Mapping (EFM) system measures these temperature variations and compensates the resistance values accordingly.
- The system utilizes bi-directional, pulsed DC excitation current to provide a dual scan of the corroded area through up to 512 differential voltage sensors to dimensionally define isolated pit defects.

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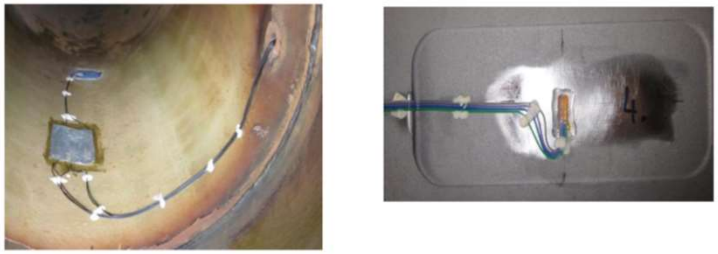
Pipe Coating, Lining and Cathodic Protection Methods

- Bituminous wrap
- Cement coating for impermeability, protection against attack
- High Performance Polyurea Spray Coatings
- Epoxies
- Polyethylene
- FBE
- Electro Magnetic Acoustic Transducer (EMAT)
- "Laproscopic" pipe repair
- Installation of sensors during repair
- Optimizing viscosity and chemical properties
- Maintenance of cathodic protection

figure 3: internal strain measurement

figure 4: external strain measurement



Source: Adria Wien Pipeline GmbH (subsidiary of OMV)

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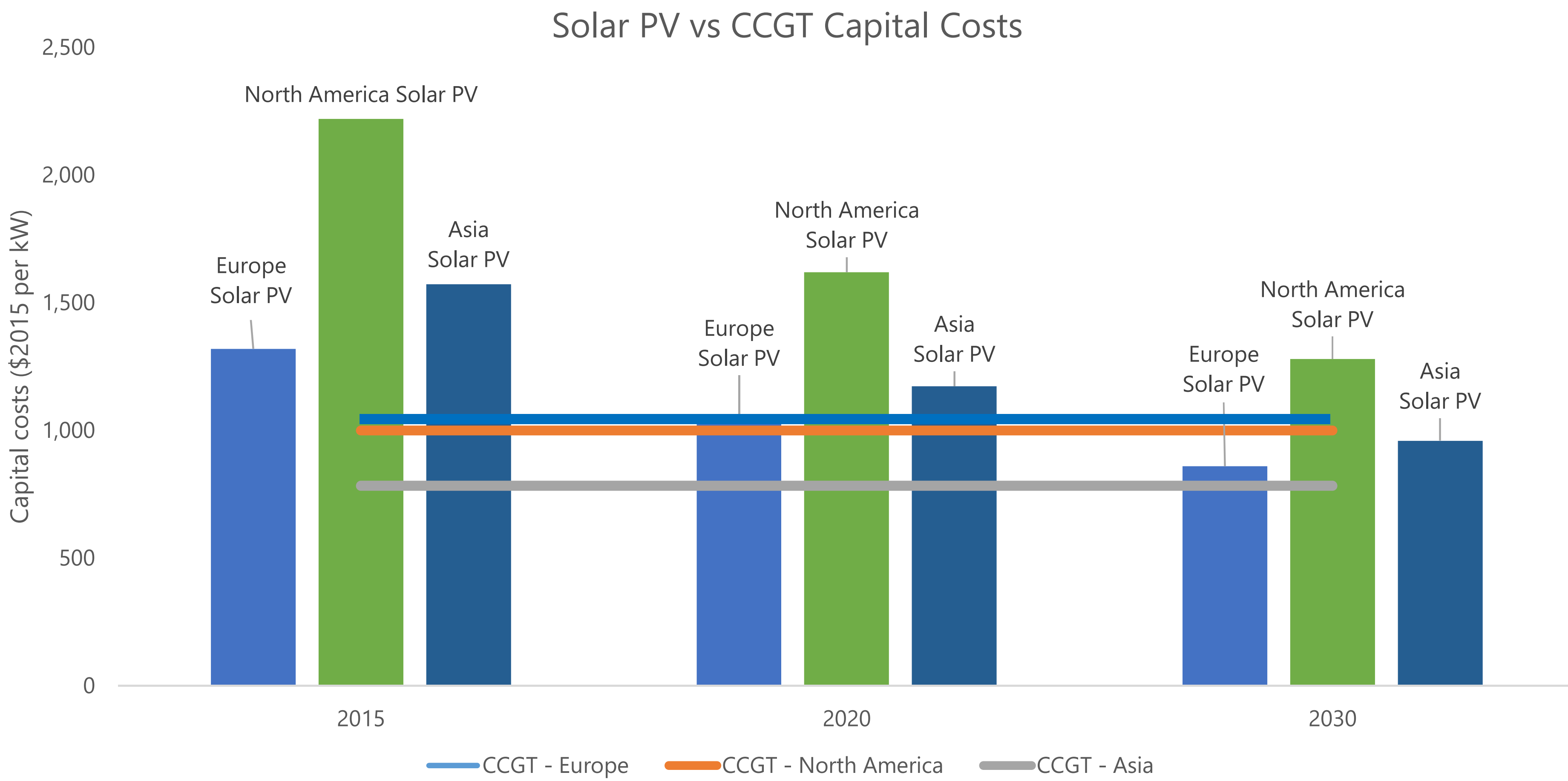
As a result, Gas/Combined Cycle is still competitive with utility-scale solar PV…



- Capital cost for Solar PV large scale are expected to decline 35% in Europe, 42% in North America, and 39% in Asia by 2020.

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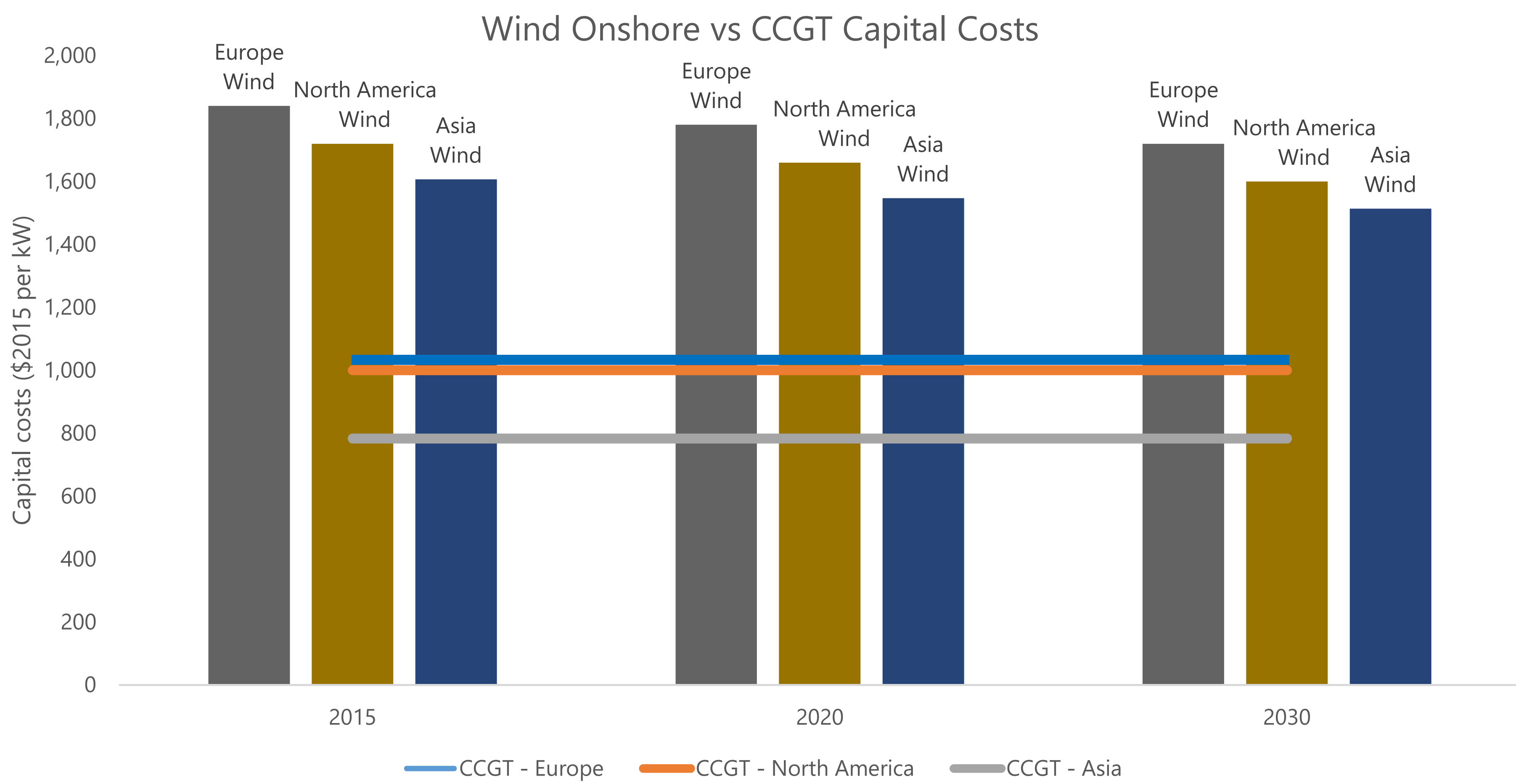
...and Wind is struggling to compete with the Gas/Combined Cycle option



- Capital cost for wind onshore projects are expected to decline 7% in Europe and North America, and 6% in Asia by 2020.

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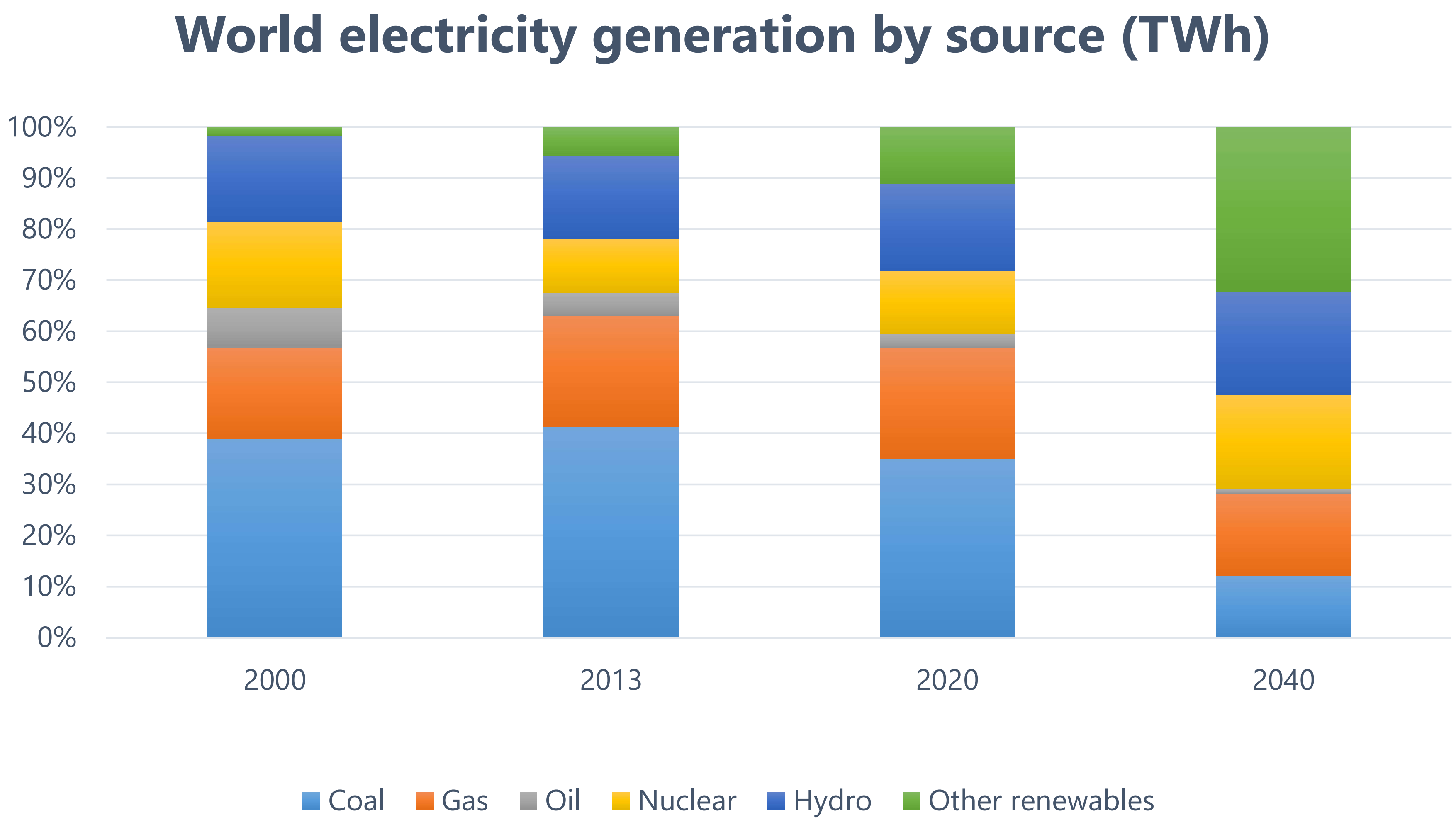
Worldwide, energy will shift toward renewables over the next 30-40 years



Source: IEA, World Energy Outlook 2015

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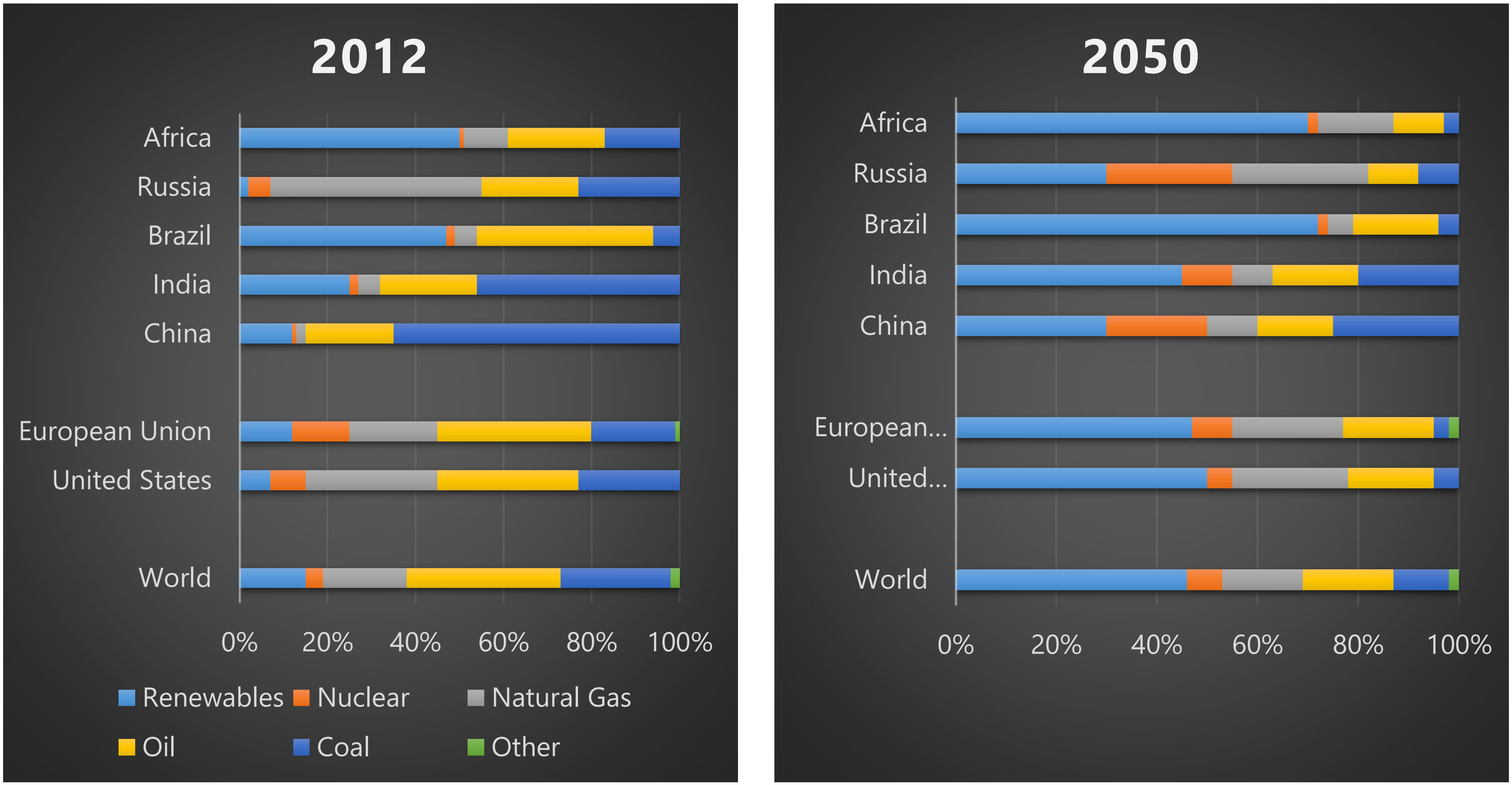
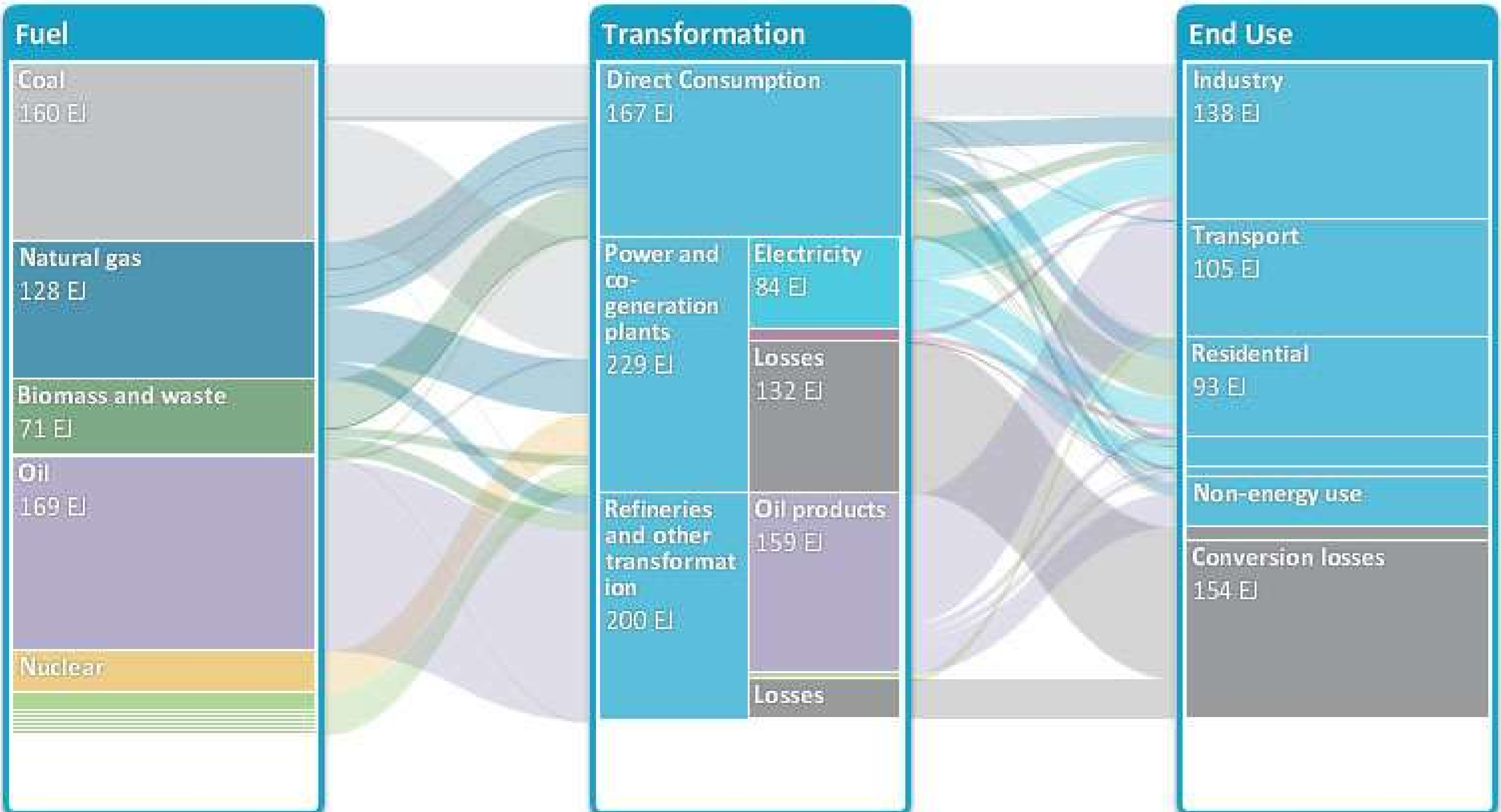
Emerging economies will leapfrog industrialized countries in renewable installations

Regional primary energy demand profiles 2012 vs 2050



2020



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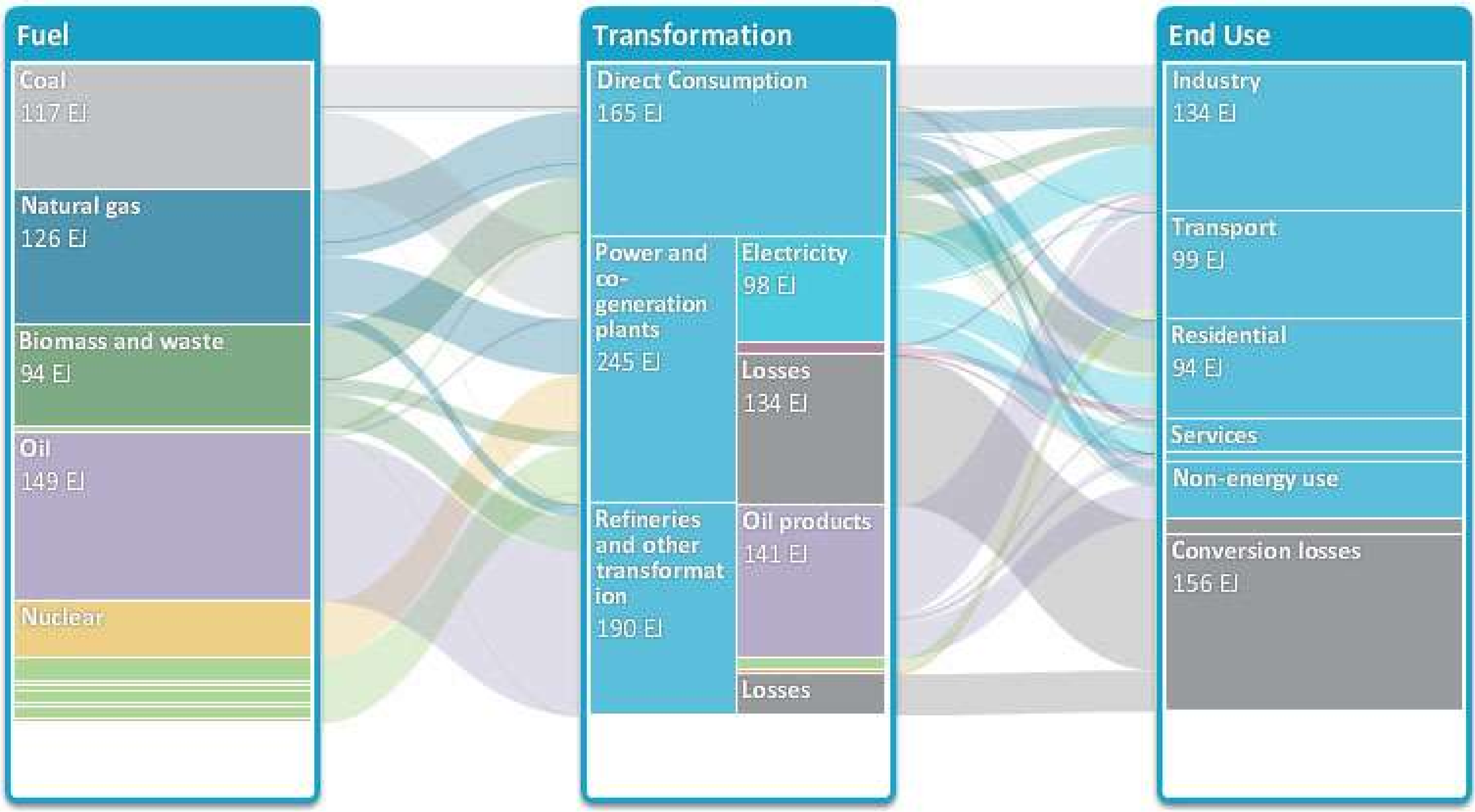
2030



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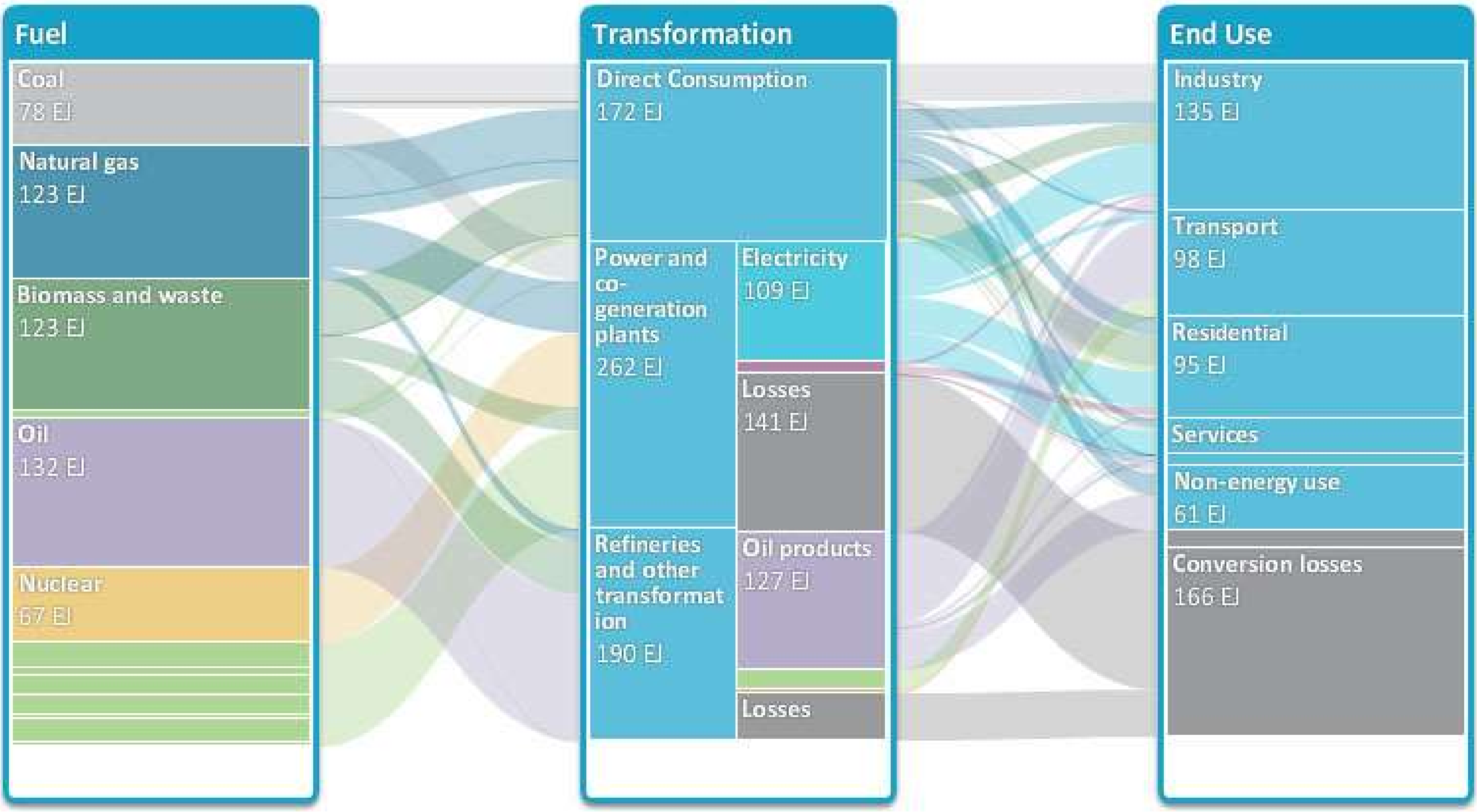
2040



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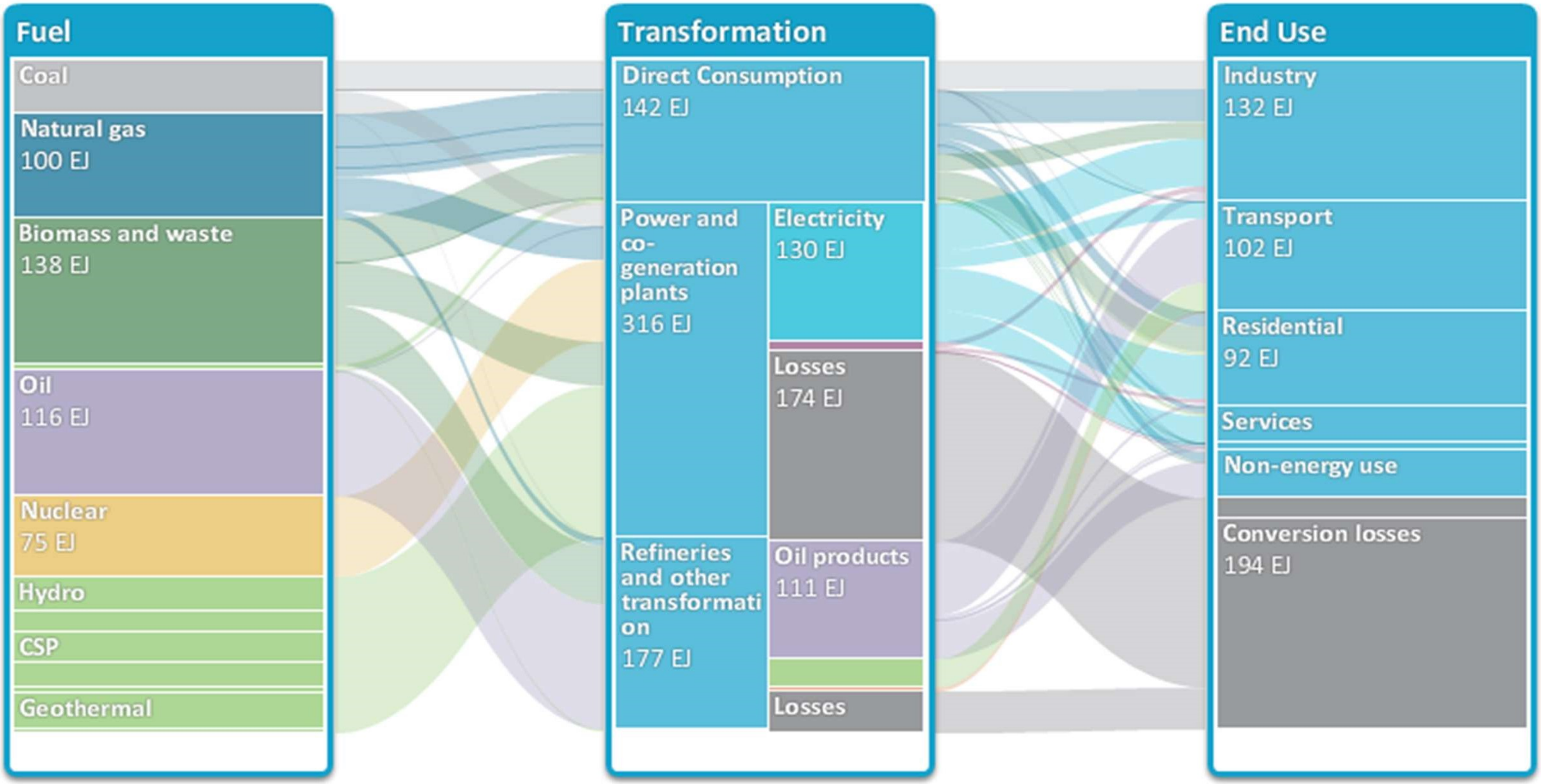
2050


Fuel
Coal
Natural gas
100 EJ
Biomass and waste
138 EJ
Oil
116 EJ
Nuclear
75 EJ
Hydro
CSP
Geothermal
Transformation
Direct Consumption
142 EJ
Power and co-generation plants
316 EJ
Electricity
130 EJ
Losses
174 EJ
Refineries and other transformati on
177 EJ
Oil products
111 EJ
Losses
End Use
Industry
132 EJ
Transport
102 EJ
Residential
92 EJ
Services
Non-energy use
Conversion losses
194 EJ

As of 2016, Canada was on a fast path toward a renewable-energy future

In 2016 Canada, US and Mexico set a goal of 50% clean power generation in North America by 2025

Canada's federal government ratified the Paris Agreement and announced its plan to establish a national price on carbon emissions, which will help drive demand for renewable energy solutions.

The federal government committed to phasing out coal-fired generation in Canada by 2030

In March 2016 Canada and the U.S. announced joint action to reduce methane emissions from the oil and gas sector by 40 to 45 per cent below 2012 levels by 2025

In August 2016, the B.C. government released its Climate Leadership Plan. The plan highlights 21 action items to reduce GHG emissions in key areas such as transportation, industry and utilities, and natural gas.

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During 2016, work progressed on four major Canadian hydropower projects under development

- Total annual generation from all hydropower facilities in Canada reached an estimated 380 TWh in 2016, with only China and Brazil exceeding this figure.
- The increasing trend will continue as dramatic cost reductions are improving the competitiveness of some renewables at both large and small scales. Today, nearly three-quarters of renewables generation, mainly in the form of hydropower, is competitive without subsidies (not including externalities).

Site C by BC Hydro	Keeyask by Manitoba Hydro	Romaine-3 and Romaine-4 by HydroQuébec	Muskrat Falls by Nalcor
• In northern British Columbia • Total installed capacity of 1,100 MW • Completion date 2024	• On the Nelson River in northern Manitoba • Will add 695 MW of new capacity • By 2021	• Romaine-3 – 395 MW, expected to be in service in 2017 • Romaine- 4 – 245 MW scheduled for completion by 2020	• In Labrador • 824 MW • Completion in 2019 • Will be the second largest hydroelectric facility in the providence

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There is a growing list of solar project in the wings, especially in Alberta

- Canada's solar electricity sector is cost competitive with other forms of electricity by 2020.
- The majority of Canada's growth is centered in Ontario, where more than 99% of Canada's solar electricity is generated.
- 21 proposed solar projects generating a total of 681 MW — about 60 times the existing provincial solar capacity — have been registered on its system access service request list as of Sept. 2016.

Vulcan Solar Project by EDF EN Canada Inc.	Blackspring Ridge project by EDF EN Canada	Suncor to build multiple solar projects
• 77.5 MW • Southern Alberta • Would be the largest solar power project in Western Canada	• 300 MW • The project is to be constructed in two phases, pending approval. The first would provide 55 MW, enough energy to power 8,800 homes, when built next year. A 22.5-MW addition in 2018 would provide enough power for another 3,600 homes.	• Suncor is in the very preliminary development stage of three proposed solar projects in Alberta • If built, these projects would add 240 megawatts of solar generation capacity • They are expected to be connected to the grid by March of 2018

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With wind project cost down 60% in 6 years, wind power economics are more compelling

- Onshore wind outlook in Canada is robust: 7.5+ GW additional capacity expected by 2020, mainly driven by programs in Quebec and Ontario.
- Awarded projects will come on line over 2017-20. Ceiling price is CAD 115 per megawatt hour (MWh) (USD 93/MWh) .
- Tenders are expected to drive more cost-effective renewable energy deployment due to competitive bidding. Forecasted estimated levelized costs of electricity (LCOEs) in Ontario for onshore wind is at CAD 75-110/MWh, taking into account improved energy yield with increasing turbine efficiency.
- In December 2014, Quebec awarded three onshore wind projects totaling 447 MW that are expected to come on line in 2016-18. The average contract price for these projects was CAD 76/MWh (CAD 63/MWh for energy and CAD 13/MWh for transmission costs) (USD 66/MWh). The price ceiling set for this tender was CAD 90/MWh, significantly lower than CAD (2009) 125/MWh set in 2009.

Ontario

- Ontario's new Large Renewable Procurement process
- > 2,000 MW of wind slated to be built in Ontario in the next few years.

Quebec

- Canada's second largest wind energy market
- In 2015 added 397 MW for a total of 3,262 MW.
- The province has another 700 MW due to come online in the next two years.

Nova Scotia

- Commissioned 186 MW in 2015 including one of the largest municipal-owned wind projects in Canada (the 14-MW Sable Wind Farm).

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Despite incursion by renewables, conventional power projects are benefiting from low gas prices, low capital costs, and existing gas-fired power gen capacity

Factor supporting the role for natural gas power generation in Canada	Lower upfront capital costs	Embedded natural gas-fired capacity
• Low natural gas prices • Lower GHG emissions compared to coal-fired power plants • Shorter construction times.	• Lower upfront capital costs than coal-fired or nuclear power plants • Ability for capacity to be built in smaller increments to better match load growth, fast start-ups to meet load changes throughout the day, and a well-developed natural gas pipeline network in Canada.	• Continued use of natural gas in cogeneration facilities for oil sands development and replacement of coal-fired units with natural gas-fired units.

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Global market factors are favoring renewables long-term; the question is ‘when’

Renewables on the Rise

- The renewable electricity market has witnessed an unprecedented acceleration in recent years, and it broke another annual deployment record in 2016.

Solar Bump

- The market’s main driver last year was solar photovoltaics, which is boosting the growth of renewables in power capacity around the world.

Economics Favoring Renewables Long Run

- As costs decline, wind and solar are becoming increasingly comparable to new-build fossil fuel alternatives in a growing number of countries.

Asian Scale Economies Will Influence Speed of Adoption

- China remains the dominant player, but India is increasingly moving to the center stage.

Low Fossil Fuel Prices, Low Capital Costs, and Pressure for Regulatory Relief Will Keep Conventionals Alive Longer Than Experts Expect

- Lower fossil fuel prices should also be considered as an opportunity to better align pricing with the true costs of energy production, in part by phasing out fossil fuel subsidies and introducing carbon pricing.

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For conventional producers, a robust strategic plan will be essential for successful adaptation

BSI's Strategy Formulation Approach

1. Internal Assessment	2. Establishment of Objective Criteria	3. Market Intelligence & Analysis	4. Strategic Fit Analysis	5. Options Definition and Evaluation	6. Implementation Planning
Stakeholder Interviews Documentation of current business model Articulation of current mission, vision, and strategy	Stakeholder interviews Identification of criteria Creation of definitions and scales for quantification Consideration of weightings Clarification of sequential and logical decision-making processes	Data gathering Quantitative market analysis (segment size, growth, forecasts) Strategic market profiling (7-point assessment, Key Success Factors)	Assessment of resource fit with target markets (customers, organization, operations, overall SWOT) Assessment of resource fit with target markets (customers, organization, operations, overall SWOT)	Development of portfolio strategies Assessment of fit with criteria Definition of each option Quantitative and financial evaluations (ROS, ROI, and NPV) Detailed assessment of fit with criteria Detailed description of each option Quantitative and financial evaluations (ROS, ROI, and NPV)	Documented vision and mission statements Development of action plan, with milestones and required enablers Recommended organization structure Recommended metrics, targets, and milestones Financial projections Implementation plan

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Comparative Economics of Combined Cycle, Solar, Wind, Hydro, and Geothermal Power

University of Calgary, Haskayne School of Business, Calgary, Alberta, Canada, October 19, 2017

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