

Electricity Generation Options:

## Energy Payback Ratio

### Definition

*Energy payback* is the ratio of total energy produced during a system's normal lifespan, divided by the energy required to build, maintain and fuel it. A high ratio indicates good environmental performance. If a system has a payback ratio between 1 and 1.5, it consumes nearly as much energy as it generates, so it should never be developed.

### Main findings

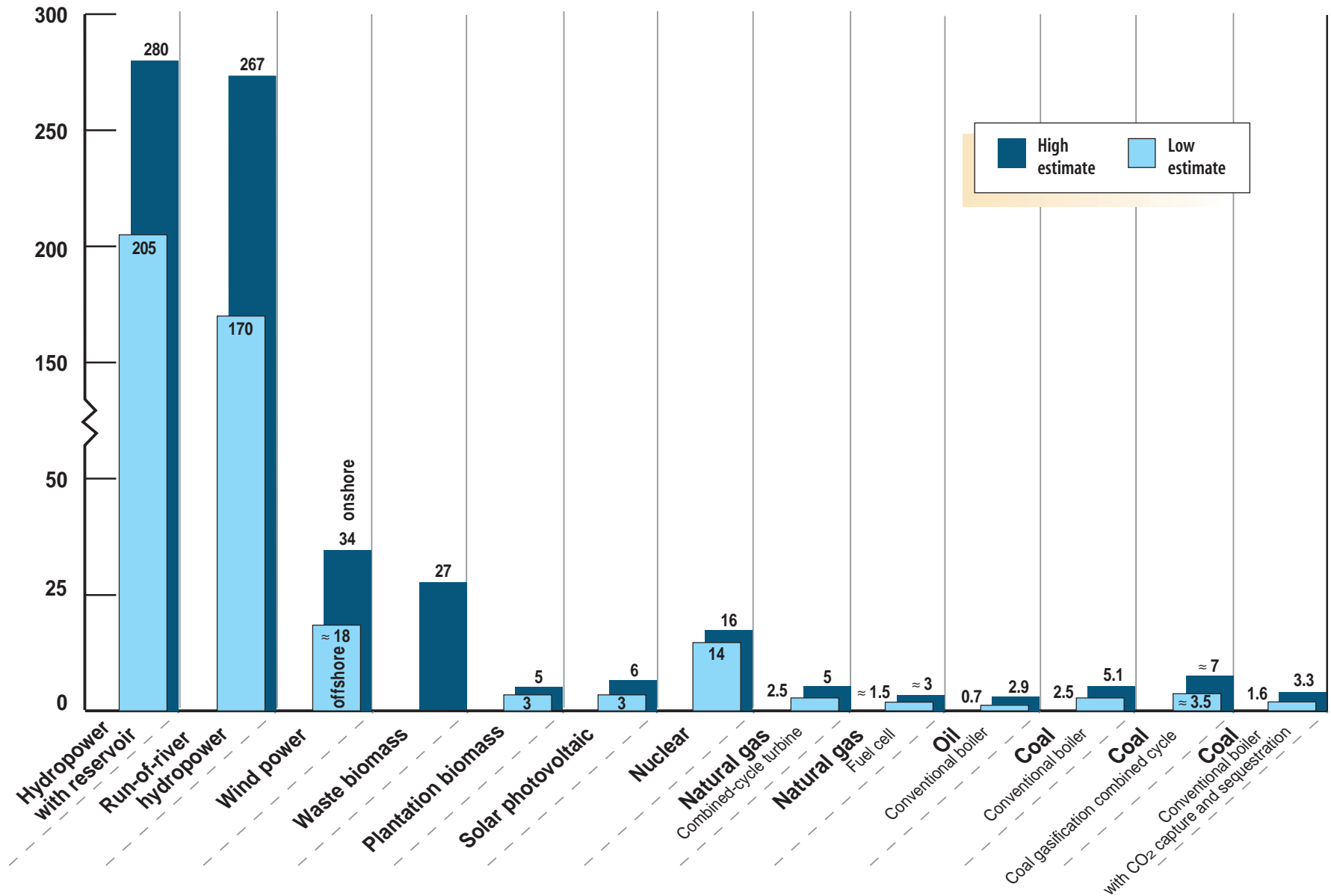
- **Hydropower** clearly has the highest performance, with ratios exceeding 170, compared to ratios between 1.6 and 7 for fossil fuels. For projects assessed in Quebec, the performance is 205 for hydro with reservoir and 267 for run-of-river hydro (assuming a lifespan of 100 years).
- Large **wind turbines** also perform very well: about 34 for good on-shore sites. However, this ratio is overestimated because the assessments do not consider the need for backup capacity to compensate for fluctuations in wind turbine output.
- **Biomass** performs well (ratio of 27) when power is produced from forestry wastes. But when trees are planted for the purpose of producing electricity, the ratio is much lower (about 3 to 5), because biomass plantations require high energy inputs. For all biomass options, the distance between the source of biomass and the power plant must be short, otherwise the energy payback ratio drops to very low values.
- For combined-cycle turbines, fueled by **natural gas**, the ratio is relatively low: between 2.5 and 5. The performance is affected by the amount of energy spent in processing the gas and transporting it over thousands of kilometres. When the power plant is located near the extraction site, the payback ratio is about 5.
- For conventional **coal-fired** generation, the performance (from 2.5 to 5.1) is greatly affected by transportation of the coal. It can also be affected by SO<sub>2</sub> scrubbing equipment, which requires natural resources such as lime that need to be extracted and delivered to the plant.
- **CO<sub>2</sub> capture and sequestration** from coal-fired power plants does not appear to be a promising technology. Its payback ratio is very low: between 1.6 et 3.3 (depending on coal transportation distance). This technology reduces the efficiency of power plants by about 25% and also uses a lot of energy to manage the CO<sub>2</sub> stream.

### Life Cycle Assessments

The data presented in this fact sheet is based on Life Cycle Assessments (LCAs) of energy options. LCAs ensure a rigorous approach when comparing energy options, because they try to compile all impacts of an option, including impacts related to building, maintaining and operating a power plant and the extraction, processing and transportation of natural resources.

The main data compiled by LCAs are atmospheric emissions and consumption of natural resources. This fact sheet shows the performance of options based on their consumption of energy resources.

## Energy Payback Ratio of Electricity Generation Options Based on Life-Cycle Assessments



## The future performance of fossil fuels

Fossil fuels already have low Energy Payback Ratios and these will probably be declining over the next decades. This is due to multiple factors:

- As the best oil and gas reserves are depleted, they tend to be replaced by wells that require a higher energy investment, as they are often located in far-away regions or under the sea. One obvious example is oil from tar sands. The process energy, mainly natural gas, required to extract oil from tar sands is five times greater than in the case of conventional oil. As a result, the Energy Payback Ratio of oil from tar sands drops from 2.9 to 0.7 if the oil is used in electricity generation. This means that directly burning the natural gas (used in the process) would generate more electricity. Therefore, the development of tar sands is only justified because oil is well suited as a fuel for the transportation sector.
- Various factors could also reduce the future performance of natural gas-fired generation. Longer delivery distances are probable. Moreover, a higher percentage of gas will be delivered by tanker ship, in the form of liquefied methane (at extremely cold temperatures). This type of delivery requires more energy than pipelines.
- Due to severe air quality problems in many countries, coal-fired plants will need to consume more energy to control emissions. There are two main methods of reducing  $\text{SO}_2$  emissions: using scrubbers (at the plant) to capture the  $\text{SO}_2$  or using low-sulfur coal.  $\text{SO}_2$  scrubbing can reduce the overall efficiency of coal-fired generation by 10 to 15%, and more energy is required to manage the sulfur wastes. In the U.S. in the last 20 years, most utilities decided not to install scrubbers and have achieved  $\text{SO}_2$  emission reductions by switching to low-sulfur coal from the Western states. Consequently, average transportation distance for coal has increased, with greater energy consumed in delivery. Thus, both approaches to controlling  $\text{SO}_2$  reduce the energy payback of coal-fired generation.
- If technologies for capturing and sequestering  $\text{CO}_2$  become commercially available, they will require huge amounts of energy. Capturing  $\text{CO}_2$  can reduce a plant's efficiency by 25% and much energy will then be required to transport and sequester the waste stream. To appreciate the size of the challenge, it is relevant to compare it with  $\text{SO}_2$  scrubbing. Coal has a sulfur content of 1 or 2% and a carbon content of 70 to 80%.  $\text{CO}_2$  capture and sequestration is therefore 50 times more difficult. Since  $\text{SO}_2$  scrubbing has often been rejected, one may question the feasibility of large-scale  $\text{CO}_2$  capture.

### Important considerations concerning level of service:

- When specific projects are compared, a rigorous assessment should consider various quality factors, such as operating flexibility and reliability. For an intermittent option such as wind power, the assessment should consider the backup power required when there is little or no wind.
- For hydropower with reservoir, comparisons are complicated by the fact that these facilities can provide services such as flood control, drinking water supply or irrigation. If a reservoir is mainly designed for irrigation, this should not be considered representative of most hydro generation.

### Why is the Energy Payback Ratio a good environmental indicator?

When a system has a low Energy Payback Ratio, it means that it consumes large amounts of energy, with associated environmental impacts. For fossil fuels, it means significant impacts related to extraction, processing and transportation of the fuel, and also at the generation site. For renewable energy, environmental impacts can arise from the construction itself.

Energy source and generation technology	Low estimate	High estimate	Source of data
<b>Renewable sources</b>			
Hydropower with reservoir	205	280	Peisajovich, 1997 = 205: La Grande, Canada Baumgartner, 1997 = 280: Marmorera, Suisse
Run-of-river hydropower	170	267	Baumgartner, 1997 = 170-221: Swiss plants Peisajovich, 1997 = 267: Beauharnois, Canada
Wind power, with 35% capacity factor	≈ 18 offshore	34 onshore	Data corrected to raise capacity factor to 35% Onshore: White, 1999 = 34 ; NREL, 2004 = 23 Offshore: ExternE, 1997: hypothesis that energy consumption is proportional to CO <sub>2</sub> emissions; offshore CO <sub>2</sub> emissions 52% greater than onshore
Waste biomass		27	Vattenfall, 1999
Plantation biomass	3 Delivery 100 km	5 Delivery 20 km	Matthews, 2000
Solar photovoltaic	3	6	Dones, 1999 = 6; Meier, 2002 = 6; Baumgartner, 1997 = 3-6
<b>Nuclear</b>			
Conventional PWR	14	16	Voss, 2001 = 14 ; White, 1999 = 16 Andsetta, 1998 = 16 (CANDU reactor)
<b>Natural gas</b>			
Combined-cycle turbine; 55% efficiency	2.5 Transportation 4,000 km	5 CCGT near the gas well	Data corrected to raise efficiency to 55% NREL, 2000 = 2.5: delivery of gas over 4,000 km Meier, 2002 = 4; 48% efficiency, average distance, US delivery
Fuel cell	≈ 1.5	≈ 3	NREL, estimate corrected to factor in gas reforming to hydrogen
<b>Oil</b>			
Conventional boiler; 35% efficiency	0.7 Tar sands	2.9 Conventional oil	National Climate Change Secretariat, Canada, 1998
<b>Coal</b>			
Conventional boiler; 35% efficiency; modern SO <sub>2</sub> scrubbing	2.5 Transportation 2,000 km	5.1 Transportation 500 km	NREL, 1999: coal transportation by train Voss, 2001 = 3.3 for 43% efficiency
Coal gasification combined cycle; 43% efficiency; SO <sub>2</sub> scrubbing	≈ 3.5 Transportation 2,000 km	≈ 7 Transportation 500 km	NREL, 1999: data corrected for increased efficiency and greater facility in scrubbing SO <sub>2</sub> (no CO <sub>2</sub> capture /sequestration)
Conventional boiler with CO <sub>2</sub> capture and sequestration	1.6 Transportation 2,000 km	3.3 Transportation 500 km	IEA, 2003: capture = efficiency reduction of 25%; + hypothesis that pumping and sequestration of CO <sub>2</sub> stream consumes 10% of energy produced

\* Energy Payback Ratio = the total energy produced during the lifespan of the system, divided by the energy required to build, maintain and fuel it. (The same ratio is called External Energy Ratio by the National Renewable Energy Laboratory, to indicate that it does not take into account the inherent energy in the fuel burned in power stations.)

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