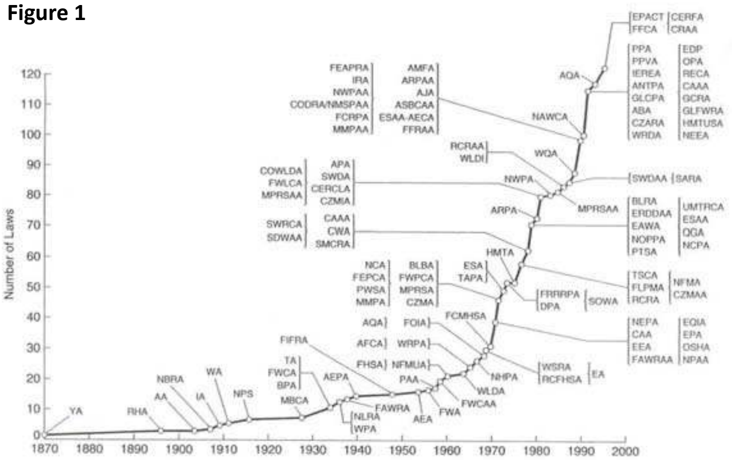
Is Sustainable Energy Development Possible?

(It's Not Easy Being Green)

Allen, D.T. and Shonnard, D.R., 2002, Green Engineering: *Environmentally Conscious Design of Chemical Processes*, Prentice-Hall, p. 65

Figure 1



The Pollution Prevention Act (PPA) states:

1. Pollution should be prevented or reduced at the source whenever feasible
2. Pollution that cannot be prevented or reduced should be recycled
3. Pollution that cannot be prevented or reduced or recycled should be treated, and
4. Disposal or other releases into the environment should be employed only as a last resort.

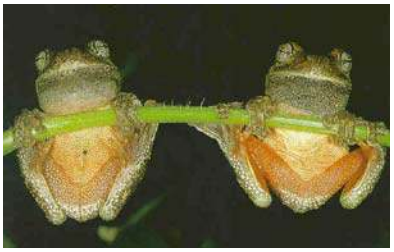
Principles of Green Chemistry

Anastas, Paul T.; Warner, John C.

Green Chemistry Theory and Practice;
Oxford University Press: New York, 1998

Definition of Green Chemistry

"The design of chemical products and processes that are more environmentally benign and reduce negative impacts to human health and the environment."



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12 Principles of Green Chemistry

1. It is better to prevent waste than to treat or clean up waste after it is formed.

2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

12 Principles of Green Chemistry

3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.

12 Principles of Green Chemistry

5. The use of auxiliary substances (solvents, separation agents, etc.) should be made unnecessary whenever possible and, when used, innocuous.

6. Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

12 Principles of Green Chemistry

7. A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.

8. Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.

12 Principles of Green Chemistry

9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. Chemical products would be designed so that at the end of their function they do not persist in the environment and instead break down into innocuous degradation products.

12 Principles of Green Chemistry

11. Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.

12. Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

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12 Additional Principles for Green Chemistry.

Gonzales, M.A., and R. L. Smith, 2003
Environ. Prog. 22, 269

12 Additional Principles for Green Chemistry.

1. Identify byproducts; quantify if possible

2. Report conversions, selectivities, and productivities

3. Establish a full mass balance for the process

4. Quantify catalyst and solvent losses

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12 Additional Principles for Green Chemistry.

5. Investigate basic thermochemistry to identify exotherms (safety)

6. Anticipate other potential mass and energy transfer limitations

7. Consult a chemical or process engineer

12 Additional Principles for Green Chemistry.

8. Consider the effect of the overall process on choice of chemistry

9. Help develop and apply sustainable measures

10. Quantify and minimize use of utilities and other inputs

12 Additional Principles for Green Chemistry.

11. Recognize where operator safety and waste minimization may be compatible

12. Monitor, report and minimize wastes emitted to air, water, and solids from experiments or processes

Definition of Green Engineering

Abraham, M., 2004, *Environ. Prog.* 23 (4), p. 266.

"The design, commercialization, and use of processes and products, which are feasible and economical while minimizing (1) generation of pollution at the source and (2) risk to human health and the environment."

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12 Principles of Green Engineering

Anastas, P. and J.B. Zimmerman, *Environ. Sci. Techol.,* vol 37 (5), p. 95A.

1. Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible.

2. It is better to prevent waste than to treat or clean up waste after it is formed.

12 Principles of Green Engineering

3. Separation and purification operations should be designed to minimize energy consumption and materials use.

4. Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.

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12 Principles of Green Engineering

5. Products, processes, and systems should be “output pulled” rather than “input pushed” through the use of energy and materials.

6. Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.

12 Principles of Green Engineering

7. Targeted durability, not immortality, should be a design goal.

8. Design for unnecessary capacity or capability (e.g., “one size fits all”) solutions should be considered a design flaw.

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12 Principles of Green Engineering

9. Material diversity in multicomponent products should be minimized to promote disassembly and value retention.

10. Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.

12 Principles of Green Engineering

11. Products, processes, and systems should be designed for performance in a commercial "afterlife".

12. Material and energy inputs should be renewable rather than depleting.

Sandestin Declaration of Green Engineering Principles

To fully implement Green Engineering solutions, engineers use the following principles:

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools

2. Conserve and improve natural ecosystems while protecting human health and well-being

Sandestin Declaration of Green Engineering Principles

3. Use life cycle thinking in all engineering activities

4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible

5. Minimize depletion of natural resources

Sandestin Declaration of Green Engineering Principles

6. Strive to prevent waste

7. Develop and apply engineering solutions, being cognizant of local geography, aspirations and cultures

Sandestin Declaration of Green Engineering Principles

8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability

9. Actively engage communities and stakeholders in the development of engineering solutions

There is a duty to inform society of the practice of Green Engineering

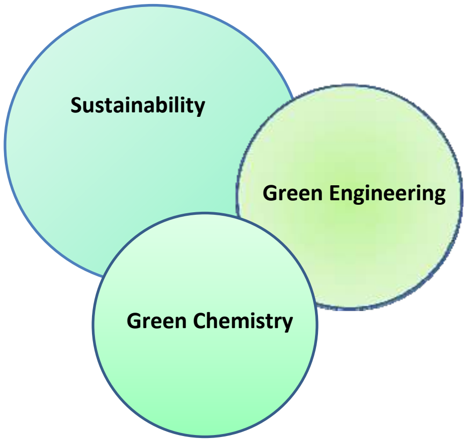
Gonzalez, M.A., and R. L. Smith, 2003, *Environ. Prog*. 22, 269

Definition of Sustainability

Brundtland Commission, 1987, United Nations

"Providing for human needs without compromising the ability of future generations to meet their needs."

Figure 2. Relationship between green chemistry, green engineering, and sustainability.



Abraham, M. 2003, *Environ. Progress* 23, 261.

Sustainability Engineering Principles

Beloff, B. et al. Eds. 2005, *Transforming Sustainability Strategy into Action: The Chemical Industry*, Wiley-Interscience, p. 189

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools
2. Conserve and improve natural ecosystems while protecting human health and well-being
3. Use lifecycle thinking in all engineering activies

Sustainability Engineering Principles

4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible

5. Minimize depletion of natural resources.

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Sustainability Engineering Principles

8. Create engineering solutions beyond current or dominant technologies; improve, innovate and invent (technologies) to achieve sustainability

9. Actively engage communities and stakeholders in development of engineering solutions

There is a duty to inform society of the practice of sustainable engineering.

Figure 3. Impact indicators used in life-cycle assessment screening of fuel additives.

Curran, Mary Ann 2003, *Environ. Progress* 22, 277.
Air Emissions (lb)
Metals in Air (lb)
Water Effluents (lb)
Metals in Water (lb)
Solid Waste lb)
Fossil Fuel Use (Btu)
Non-Fossil Fuel Use (lb)
Water Use (gal)
Land Use (acres)
Transportation (miles)
Agrochemical Use (lb)
CO_2 Uptake (lb)

Figure 4. Some of the values and benefits derived from corporate sustainable development programs.

- ☐ License to operate
- ☐ Risk reduction
- ☐ Improved productivity/efficiency
- ☐ Reduction of costs related to manufacturing and commercial sites
- ☐ Stimulus for innovation/new products and services
- ☐ Increased market share
- ☐ New alliances
- ☐ Community goodwill
- ☐ Enhanced reputation
- ☐ Enhanced access to capital/markets
- ☐ Increased shareholder value

Beloff, B., Tanzil, D., and M. Lines, 2004, *Environ. Prog*. 23, 271.

Case Studies

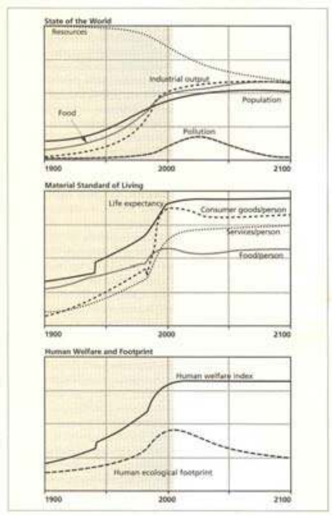
World Sustainability

Fossil Fuel Resources

Acetylene (Carbide Based)

World Sustainability at 2030

Figure 5



Meadows, D. et al. 2004, *Limits to Growth*: The 30-Year Update, Chelsea Green Publishing, Chapter 8

World 3-03 Scenario Variables & Scales

Meadows, D. et al. 2004, *Limits to Growth*: The 30-Year Update, Appendix 1, pp. 285-288		
State of the World		
Variable	**Low Value**	**High Value**
Population	0	12 X 10^{9}
Total Food Production	0	6 X 10^{12}
Total Industrial Production	0	4 X 10^{12}
Index of Persistent Pollution	0	40
Nonrenewable Resources	0	2 X 10^{12}

World 3-03 Scenario Variables & Scales

Meadows, D. et al. 2004, *Limits to Growth*: The 30-Year Update, Appendix 1, pp. 285-288		
Material Standard of Living		
Variable	**Low Value**	**High Value**
Food Per Capita	0	1,000
Consumer Goods Per Capita	0	250
Services Per Capita	0	1,000
Life Expectancy	0	90

World 3-03 Scenario Variables & Scales

Meadows, D. et al. 2004, *Limits to Growth*: The 30-Year Update, Appendix 1, pp. 285-288		
Human Welfare and Ecological Footprint		
Variable	**Low Value**	**High Value**
Human Welfare Indicator	**0**	**1**
Human Ecological Footprint	**0**	**4**

Indicators of Human Welfare and Ecological Footprint

"Human Welfare" is quality of life of the average global citizen in its broadest sense, including both material and immaterial components.

Meadows, D. et al. 2004, *Limits to Growth*: The 30-Year Update, Appendix 2, pp. 289-293

Indicators of Human Welfare and Ecological Footprint

Quantitatively HDI (by United Nations Development Program)

Human Development (HDI) is a summary measure of a country's <u>average achievement</u> by three (3) basic dimensions of human development:

Meadows, D. et al. 2004, *Limits to Growth*: The 30-Year Update, Appendix 2, pp. 289-293

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1. A long and healthy life, as measured by life expectancy at birth
2. Knowledge, as measured by the adult literacy rate (2/3) and combined primary, secondary and tertiary gross enrollment rate (1/3)
3. A decent standard of living, as measured by GDP per capita (in PPP-$, purchasing power parity US dollars)

Indicators of Human Welfare and Ecological Footprint

"Human Ecological Footprint" is total environmental impact placed on the global resource base and ecosystem by humanity.

Meadows, D. et al. 2004, *Limits to Growth*: The 30-Year Update, Appendix 2, pp. 289-293

Indicators of Human Welfare and Ecological Footprint

Quantitatively EF (Mathis Wackernage, et al, 1990's)

EF (Ecological Footprint) Ξ Land area necessary to provide for the current way of life (w/average hectacres)

Where land area is total cropland, grazing land, forestland, and, fishing grounds, and built-up land needed to maintain a given population at a given lifestyle; plus the forest land needed to absorb the carbon dioxide emissions from the fossil energy used by the population.

***Values published (biannually) by World Wide Fund for Nature**

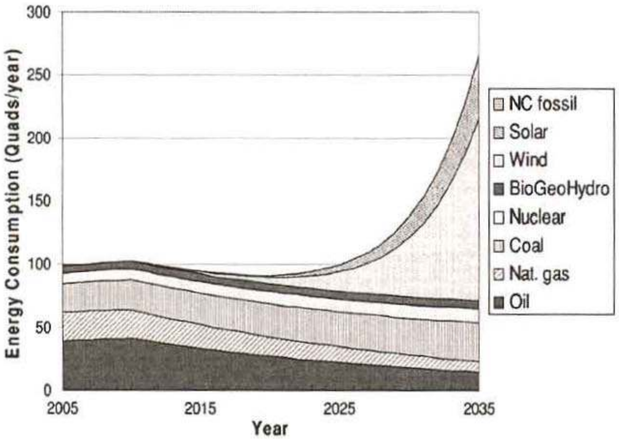
World Sustainability at 2030

“tool”	concept (conscious operation)
1	Visioning
2	Networking
3	Truth-telling
4	Learning
5	Loving

Meadows, D. et al. 2004, *Limits to Growth*: The 30-Year Update, Chelsea Green Publishing, Chapter 8

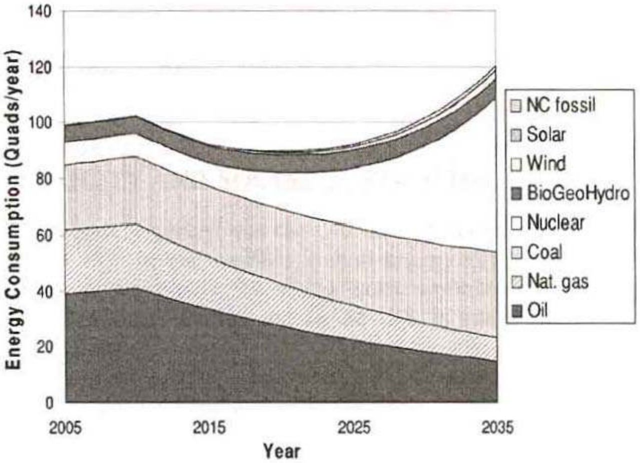
Fossil Fuel Resources

Figure 6. The green energy future scenario. Solar and wind energy grow at 25%/yr, while nuclear power and coal as energy sources grow at 1%/yr as is currently the case. Finally, nonconventional oil and gas development are not pursued and therefore too small to be visible in the plot.



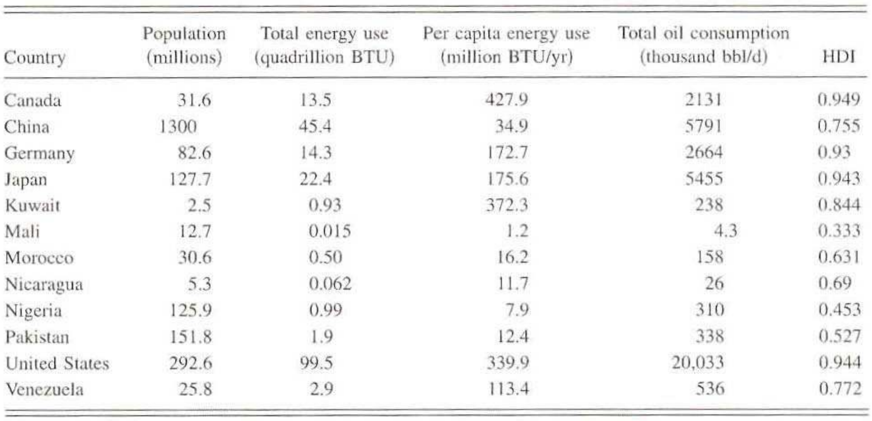
Brecha, Berney, and Craver, *Am. J. Physics*, Vol. 75, No. 10, October 2007

Figure 7. The nuclear-supplemented fossil-fuel energy future scenario. Wind energy grows at 10%/yr and coal grows at 1&/yr. while nuclear power as an energy sources increases at 10%/yr beginning in 10 years to allow for ramp-up. Solar is too small to be visible.



Brecha, Berney, and Craver*, Am. J. Physics*, Vol. 75, No. 10, October 2007

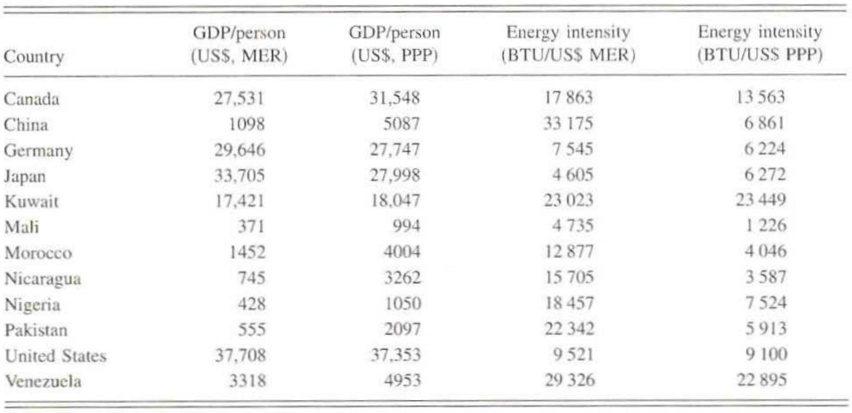
Total and per capital energy use for nine selected countries. The Human Development Index (HDI) is a rough measure of standard of living. In general, higher HDI correlates with higher per capita energy use.



Country	Population (millions)	Total energy use (quadrillion BTU)	Per capita energy use (million BTU/yr)	Total oil consumption (thousand bbl/d)	HDI
Canada	31.6	13.5	427.9	2131	0.949
China	1300	45.4	34.9	5791	0.755
Germany	82.6	14.3	172.7	2664	0.93
Japan	127.7	22.4	175.6	5455	0.943
Kuwait	2.5	0.93	372.3	238	0.844
Mali	12.7	0.015	1.2	4.3	0.333
Morocco	30.6	0.50	16.2	158	0.631
Nicaragua	5.3	0.062	11.7	26	0.69
Nigeria	125.9	0.99	7.9	310	0.453
Pakistan	151.8	1.9	12.4	338	0.527
United States	292.6	99.5	339.9	20,033	0.944
Venezuela	25.8	2.9	113.4	536	0.772

Brecha, Berney, and Craver, Am. J. Physics., Vol. 75, No. 10, October 2007

Economic energy intensity determined by two different measures for nine selected countries. Gross Domestic Product (GDP) can be measured using either market exchange rates (MER) or purchasing power parity (PPP).



Country	GDP/person (US$, MER)	GDP/person (US$, PPP)	Energy intensity (BTU/US$ MER)	Energy intensity (BTU/US$ PPP)
Canada	27,531	31,548	17 863	13 563
China	1098	5087	33 175	6 861
Germany	29,646	27,747	7 545	6 224
Japan	33,705	27,998	4 605	6 272
Kuwait	17,421	18,047	23 023	23 449
Mali	371	994	4 735	1 226
Morocco	1452	4004	12 877	4 046
Nicaragua	745	3262	15 705	3 587
Nigeria	428	1050	18 457	7 524
Pakistan	555	2097	22 342	5 913
United States	37,708	37,353	9 521	9 100
Venezuela	3318	4953	29 326	22 895

Brecha, Berney, and Craver, Am. J. Physics., Vol. 75, No. 10, October 2007

This is profound:

> "…the Club of Rome, which has since been updated twice. Without going into the details of why this work should still be read, the main points are borne out by the calculations presented in this paper: fossil-fuel resources are finite, exponential growth cannot be sustained in a finite ecosystem, the population increases are placing severe pressures on both the ecosystem and on natural resource supplies."

Brecha, Berney, and Craver, Am. J. Physics., Vol. 75, No. 10, October 2007

A Sustainable Fuel Process-Acetylene

Reaction	Chemical Reactions: acetylene from limestone and charcoal
Biomass Pyrolysis	$C_xH_yO_z \xrightarrow[\text{heat}]{} C(s)$ + Volatiles
Calcination	$CaCO_3 \xrightarrow[\text{heat}]{} \underset{\text{(ime)}}{CaO} + CO_2(g)$
Reduction	$CaO + 3\,C(s) \longrightarrow CaC_2(s) + CO(g)$
Acetylene Generation	$CaC_2(s) + H_2O(\ell) \longrightarrow C_2H_2(g) + \underset{\text{(lime)}}{CaO}$
Combustion	$C_2H_2(g) + 2.5O_2 \longrightarrow 2\,CO_2(g) + H_2O$

continued

Comments: (Acetylene Fuel)

- Net thermodynamics energy – positive
- Carbide preparation requires
  - 3100 kWh/tonne
  - Solar/wind energy
- $CO_2(g)$ emissions will return to charcoal via trees and pyrolysis
- Limestone is widely distributed
  - Carrier for carbon
  - Lime, recycle or reuse
- Patents exist for acetylene fuel

Thank you for your attention!

Questions?