Doctor Honoris Causa Speech

Chemical Engineers: Helping to Solve the World Challenges in Energy

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Abstract

This presentation will discuss the various sources of energy the world uses to meet the current 16 terawatt demand. This demand will increase to around 36 terawatts by 2050 when alternative energy sources will be needed to meet the world's energy requirement. Research areas in which chemical and other engineers can help meet this challenge will be discussed along with underlying scientific principles.

Rector Joseph Anton Ferré Vidal, Faculty and Students of Rovira i Virgili University and distinguished guests, I am so much honored to receive the *doctor honoris causa* from your distinguished university. It is the greatest honor I have ever received. Having spent this past week giving lectures, and meeting faculty and students, I have been able to see firsthand the high quality of your programs, faculty, and students.

Today I would like to discuss world energy needs and how chemical engineers can help meet these needs. First, let's review examples of the scales of energy as shown in Figure 1.

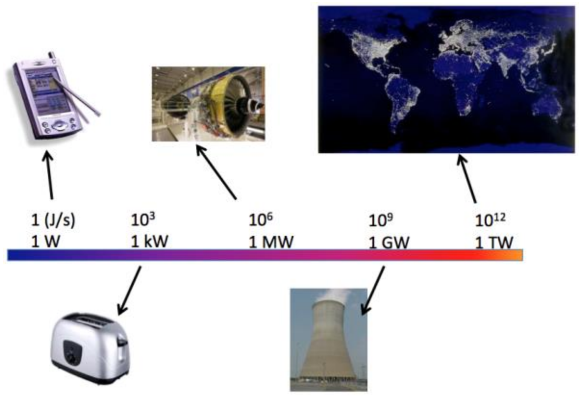


Figure 1. The Scale of Today's Energy

To power a cell phone requires 1 watt (1 joule per second); to power a toaster requires 1 kilowatt (10^3); to power a jet engine requires 1 megawatt (10^6); the power from a nuclear energy plant is a gigawatt (10^9); the power required to sustain all the lights in the world turned on at the same time is 1 terawatt (1 TW). The world's demand for energy is currently 16 terawatts. Even at a 16 TW energy level, there are still approximately 2 billion people who don't have direct access to energy.

The primary sources of energy that currently make up the 16 terawatts are shown in Figure 2.

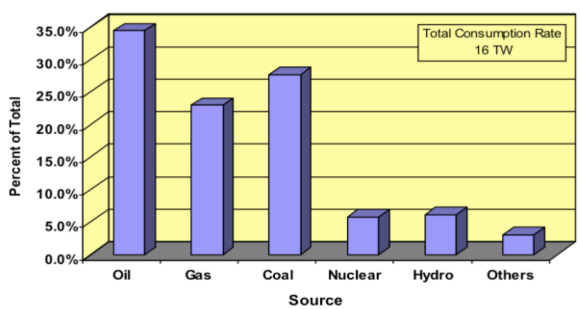


Figure 2. World's Sources of Energy

We see that approximately 85% of our current energy sources are fossil fuels with nuclear, hydro and other sources supplying the remainder. Most of the consumption of oil results from transportation and we see from Figure 3 that with the increased usage of automobiles in China and India, the consumption of oil is projected to increase by a factor of 3 by 2050.

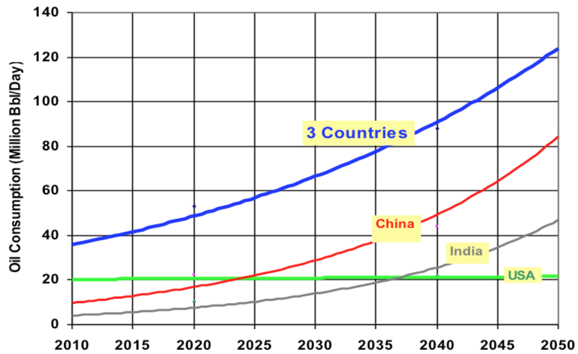


Figure 3. Projected Oil Consumption

Figure 4 shows the consumption of oil as a function of time up to 2015. After 2015, we see there are three scenarios for the projected production of oil between 2015 and 2050. The best

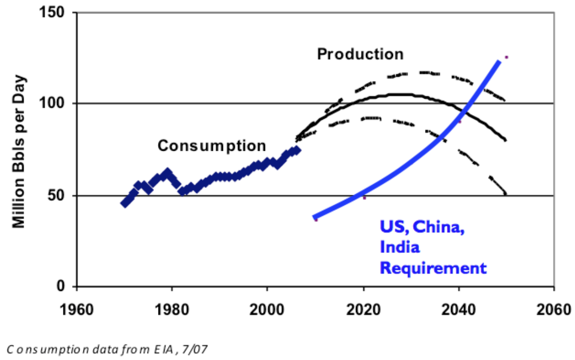


Figure 4. World Oil Consumption and Production

expected projection in oil production is shown by the top dashed line and the worst case projection is shown by the bottom dashed line. The actual projection will depend on such things as newfound petroleum sources, improved recovery, etc. Superimposed on this plot is the expected demand for oil between 2015 and 2060. We see that we will reach a "critical" point at which the projected demand exceeds the projected production somewhere between 2035 (worst case scenario) and 2050 (best production case). This intersection where the production cannot meet the demand could be a tipping point in world stability as petroleum and fossil fuels will not be able to meet the increased demand in energy.

The world's population will increase from its current level of 7+ billion to 9+ billion in 2050 (Figure 5). This increase in population has been predicted to result in the energy demand to increase by as much as two and a half times its current 16 TW level by 2050. So how will we be able to meet this demand?

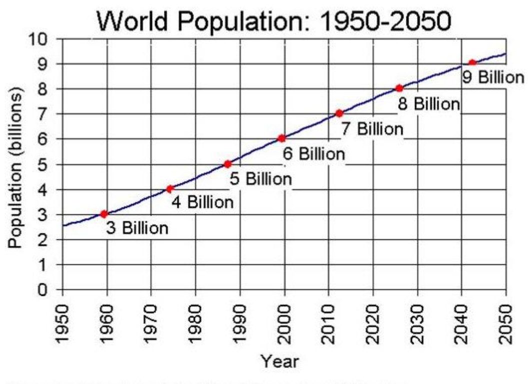


Figure 5 The "Crowded Planet"

Figure 6 shows the terawatts supplied by fossil fuels, nuclear and renewables between 2005 and 2050. The yellow band represents fossil fuels, the red-purple band nuclear and the blue-purple band renewables. When we look at the energy nuclear plants can supply, we note that to just have nuclear remain at the same percentage of the total energy in 2050 as it was in 2005, we would have to increase nuclear energy output to 1.91 terawatts. This increase would require building a 1200 megawatt nuclear power plant every 12 days from now until 2050. Therefore neither nuclear or oil will be able to provide the unmet balance shown in Figure 6.

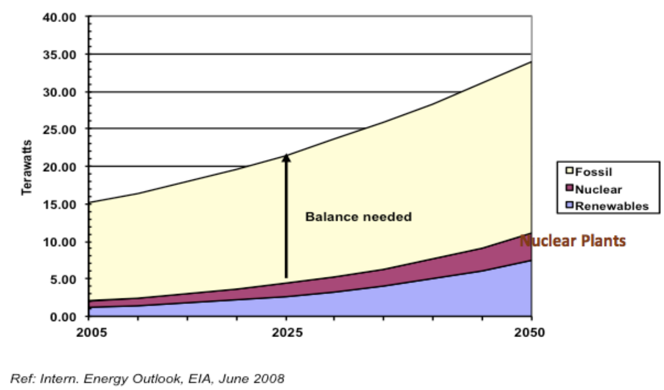


Figure 6 Energy Supplied form Fossil Fuels, Nuclear and Renewables.

The various energy sources (namely hydro, wind, geothermal, biomass nuclear and solar) that are expected to help meet the energy demand by 2050 are shown in Figure 7.

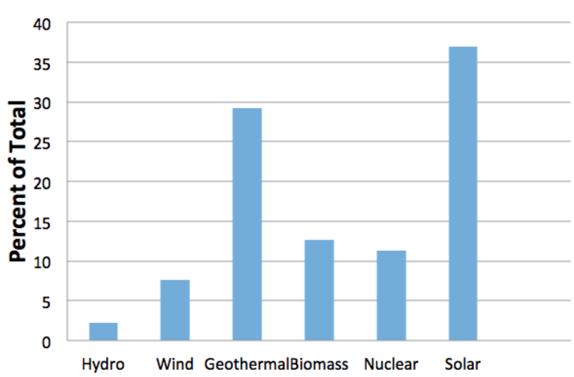
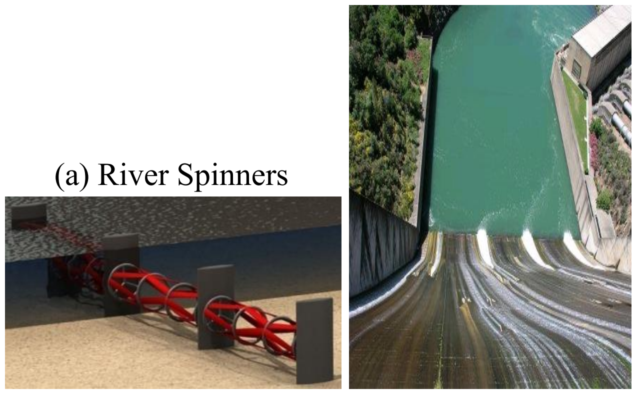


Figure 7. Alternative Energy Contributions in 2050

Let us consider each of these sources individually moving from left to right in Figure 7.

Hydroelectric

All water flow on the planet combined would produce only 4.6 TW. However, of that total of 4.6 TW, only 1.6 TW is technically feasible and of that 0.9 TW is economically feasible while 0.6 TW is currently harvested. However, I would like to note the river spinners shown in Figure 8a that are connected to an electrodynamic generators could produce much needed electricity in the rural areas of third world countries.



(a) River Spinners (b) Dams

Figure 8. Hydroelectric Power Sources

Wind Energy

All of the potential wind energy in the world combined could contribute 2-3 terawatts of the 34 terawatts needed in 2050 to the total required. Consequently, wind energy could contribute as much as 10% of the total. Figure 9 shows two different devices for collecting wind energy: turbines and spinners.

(a) Turbines (b) Spinners

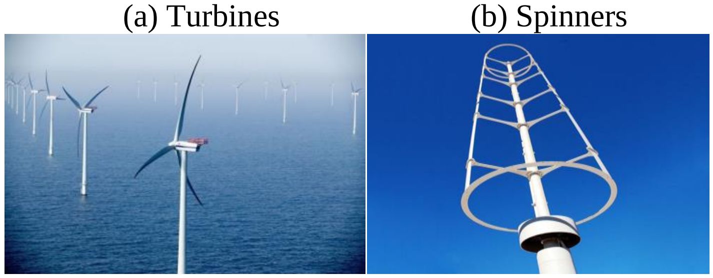


Figure 9. Wind Energy

The downside of harvesting wind energy is that the collecting devices are not environmentally friendly to birds, especially the turbines (9a) as one observes many dead birds in the proximity of the turbines. To make collecting devices more environmentally friendly to birds, spiral spinners were developed; however, they do not generate nearly as much power as the turbines. Spiral spinners are currently being used at the Detroit Metropolitan Wayne County Airport (DTW), 25 miles from my hometown, Ann Arbor, Michigan.

Geothermal Energy
Geothermal energy (Figure 10) has great promise in helping meet the estimated demand for 2050. The total potential geothermal energy from all continents is 11.6 terawatts, assuming 100% heat engine efficiencies. While 100% is not realistic at this point, chemical engineers have the background in fluid mechanics, thermodynamics and heat transfer to improve the technology for harvesting geothermal energy.

Figure 10. Geothermal Energy

Figure 11 shows a schematic diagram of how energy is harvested from a geothermal well. Here a water injection well and several production wells are drilled down into the hot porous formation. The water from the injection well then flows through the porous media, absorbing heat from the hot porous rock. The injected water that has been heated eventually reaches a production well where it flows to the surface. On the surface steam and hot water are passed through turbines and heat exchangers to recover the energy.

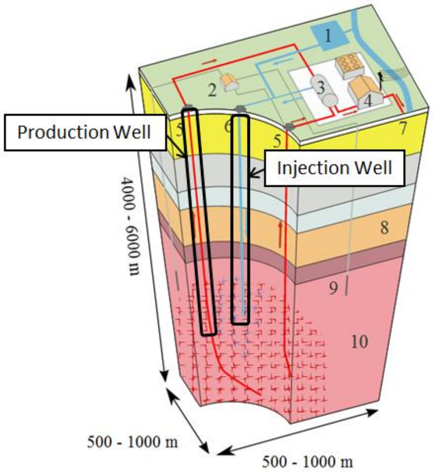


Figure 11. Geothermal Energy Resources

Solar Energy
The next energy source shown in Figure 7, solar, may hold the best promise for the future and for long term sustainability. It also presents great challenges on how to harvest it. The earth receives 174,000 terawatts of energy from the sun. As a result, 1 hour of sun is equal to 1 year of energy

consumption. Recall the current world energy demand is 16 TW. There are many types of solar energy as shown in Table 1 and we will discuss each type individually.

Table 1 Types of Solar Energy

• *Solar Thermal*
Absorption
Concentrated Solar Power (CSP)
• *Solar Voltaic*
• *Solar Chemical*
• *Solar Photo Catalytic*
Water Splitting

<u>*Solar Thermal Absorption*</u>

First, let's look at absorption, with a focus on heating an office building or a home. Figure 12 shows a solar panel on top of a house that absorbs heat from the sun causing the temperature of the panel to rise. A heat exchange fluid, such as ethylene glycol, passes through the panel and flows down a pipe into the house into a heat exchanger contained in a buffer storage tank. The heat exchanger transfers energy from the hot ethylene glycol to heat water that can be drawn from the tank as needed. If weather conditions don't permit sufficient energy to heat the water, additional heating is supplied electrically. In addition, the fluid passing through the solar panel could be also passed through heat exchange radiators to heat the air in the houses.

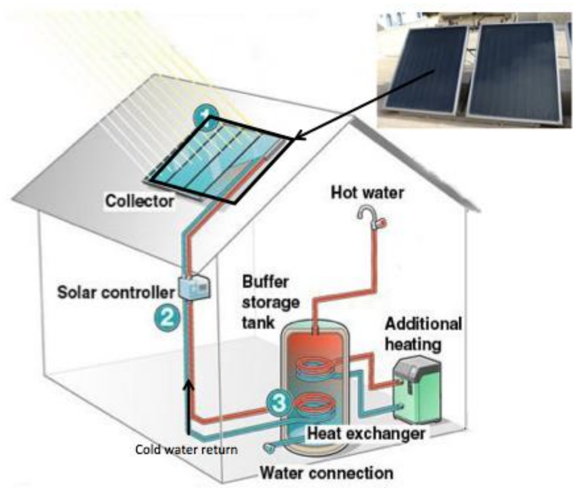


Figure 12. Solar Thermal Absorption – Heating Home Water

Two different types of solar collectors are shown in Figure 13. The flat panel and the Sydney evacuated tubes. The Sydney tubes (which are used in China and Europe) are more efficient because there is less of a convective heat loss from the collector.

(a) (b)

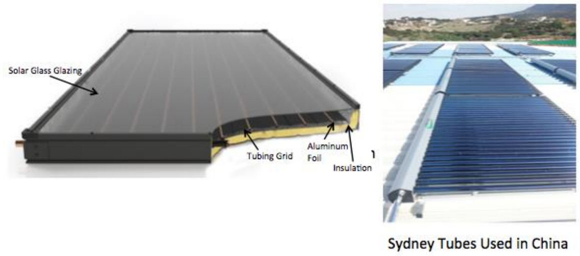


Figure 13. (a) Solar Thermal Collector and (b) Solar Thermal Evacuated Tubes

<u>Solar Thermal Concentrated Solar Power (CPS)</u>

Another type of solar thermal energy is the Concentrated Solar Power (CSP) system shown in Figure 14. This solar furnace at Odeillo the French Pyrenees uses a gigantic mirror to focus on the sun's rays to a very small area where temperatures can reach 3800 degrees Celsius. These high temperatures can be used to accelerate chemicals in reactions as will be discussed below in the modular CSP collectors.

Figure 14. Solar Thermal: Concentrated Solar Power (CSP)

Figure 15 shows a modular collector of concentrated solar power at the ENREL site near Denver, Colorado. Here, reflecting mirrors turn as the sun moves across the sky to concentrate the energy in a solar thermal reactor located at the top of the column in the middle of each module.

Figure 15 Modular CSP

This reactor uses biofuels such as switch grass shown in Figure 16 as the raw material to produce syngas.

Figure 16. Switch grass: Biofuel for Feedstock CSP Reactor

The switch grass is pulverized and fed into the solar thermal chemical reactor shown in Figure 17 where reactions such as

$$\text{(1) Cellulose:}\quad C_6H_{10}O_5(C) + H_2O(W) \rightarrow 6H_2 + 6CO$$

$$\text{(2) Lignin:}\quad C_{10}H_{12}O_3(L) + 7H_2O(W) \rightarrow 13H_2 + 10CO$$

take place. Research on this reactor is currently being carried out by Professor Al Weimer and his students at the University of Colorado.

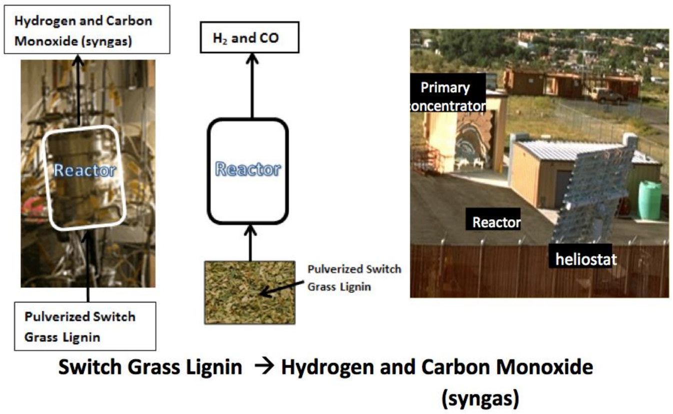


Figure 17. Solar Thermal Reactor, University of Colorado

Because of the high temperatures in the reactor of around 1200-1400°C, the biofuel is completely consumed to produced hydrogen and carbon monoxide (Syngas). Syngas can then be used in Fischer-Tropsch reactions to produce a multitude of organic chemicals. This solar thermal reactor and reactor system will provide a wealth of research products for engineering faculty and students.

Solar Voltaic

Solar voltaic cells produce direct electricity current from sunlight. A solar voltaic collector panel with an application to power parking meters in downtown Ann Arbor, Michigan is shown in Figure 18. A 1 kW photo voltaic system substitute for 150 lbs of coal and prevents 300 lbs of CO_2 from entering the atmosphere. While most of the research on photo voltaic can be found in physics and electrical engineering departments, chemical and materials science engineers are working on solar voltaic surface materials such as mono and poly- crystalline Si, amorphous Si, CdTe, $CuIn_xGa_{1-x}Se_2$ (CIGS), etc. to increase their efficiency.

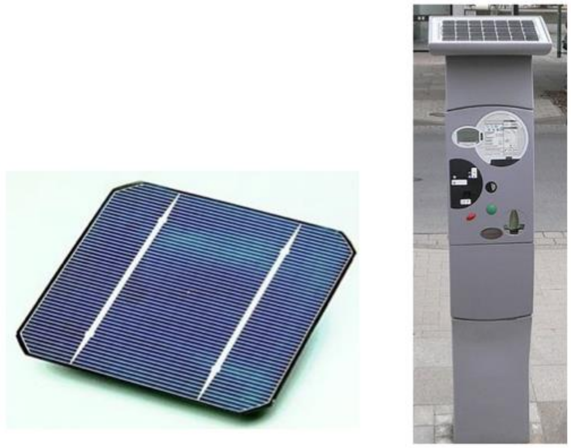


Figure 18. Solar Voltaic Power

Figure 19 shows the largest photo voltaic plant in the world near Sarnia, Ontario in Canada. This solar voltaic plant produces 97 megawatts of energy.

Figure 19. Solar Voltaic Power. The largest photovoltaic power plant in the world

Solar Toilet

While reviewing the literature on solar voltaic applications, I came across a solar toilet powered by a battery that is continually charged by the sun using a solar voltaic panel. A photograph of the solar toilet is shown in Figure 20. This technology could greatly improve sanitation and the spreading of diseases in rural areas of developing countries.

Figure 20. Solar Toilet: For Rural Locations in Developing Countries

A diagram of the system for processing solid and liquid waste can be seen in Figure 21. Here the solid and liquid wastes are first discharged to an anaerobic bacteria holding tank, which begins to break down the waste into carbon dioxide, hydrogen acetate, methane, alcohols and other products. The resulting sludge is passed on to an electrochemical reactor that operates as a reverse fuel cell. The reverse fuel cell uses a small car type battery that is recharged by a solar photo voltaic panel. The battery generates a current (electrons) that is passed through the reactor to produce chlorine to sterilize the waste as shown in Figure 22. The top photo to the right of the schematic of the electrochemical reactor shows the yellow liquid entering the reactor and the bottom photo shows the clear liquid exiting the reactor.

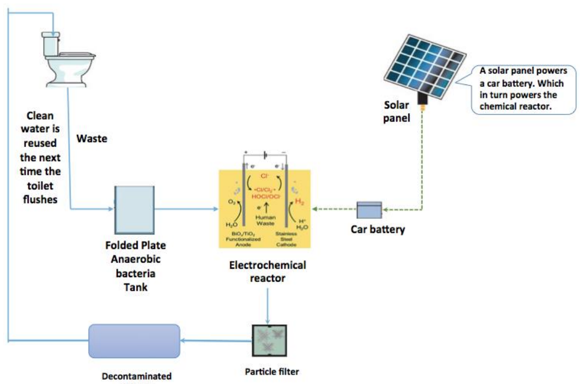


Figure 21. Solar Toilet

After exiting the electrochemical reactor, the sludge like material is filtered and the water returned to the toilet.

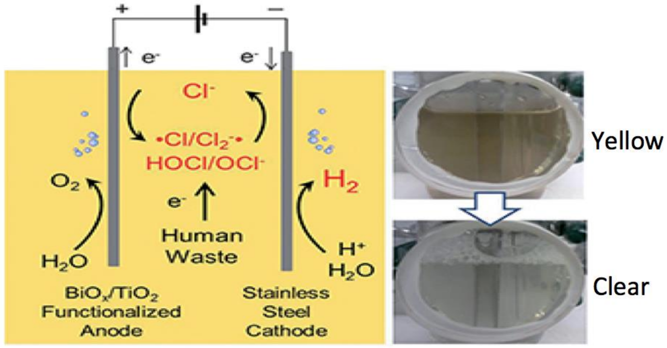
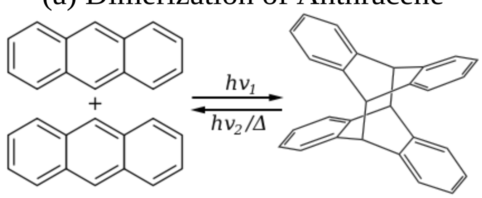


Figure 22. Solar Toilet Reactions

Solar Chemical

Solar Chemical is a fruitful area of research area for both chemists and chemical engineers. The goals are to find chemicals with large heats of reaction and to design reactors that can be used to store and release energy. In solar chemical energy storage, the sunlight causes a chemical reaction to take place in the forward direction to form a compound with a large heat of reaction. Examples of two solar chemical reactions are shown in Figure 23. Here, the sunlight causes (a) anthracene to dimerize and (b) azobenzene to isomerize. After absorbing the sun's energy and storing it in the chemical species of dimers and isomers, the energy can be released when the temperature is raised and the reaction proceeds in the reverse direction. The use of novel reactors to take advantage of this technology is also needed.

(a) Dimerization of Anthracene



(b) Azobenzene Unit Isomerization

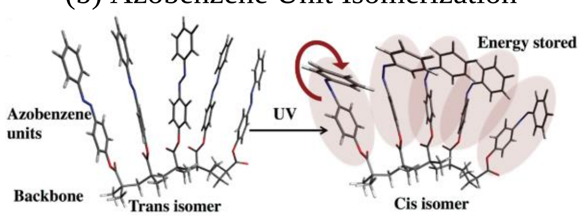


Figure 23. Solar Chemicals

Photo Catalysis

In this area, chemical engineers and materials scientists have golden opportunities to carry out research to find materials that when exposed to sunlight will split water into hydrogen and oxygen. One such material is nickel ferric oxide ($NiFe_2O_4$) shown in Figure 24. As can be seen in Figure 24, when $NiFe_2O_4$ is exposed to sunlight. Step 1 takes place and $NiFe_2O_4$ releases oxygen and forms iron (11) oxide, iron (111) oxide and nickel oxide as shown in Figure 24. The resulting oxide material will then be reacted with water in Step 2 to regenerate $NiFe_2O_4$ and release hydrogen. As can be seen in Figure 24 last reaction causes the material to be returned to its original state $NiFe_2O_4$.

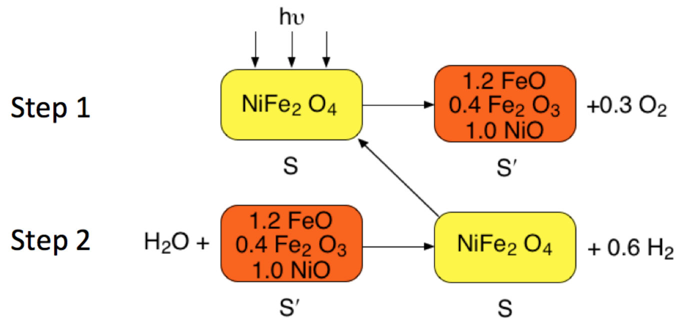


Figure 24. Photocatalysis: Solar Energy Conversion: Water Splitting

Fuel Cells
The most environmentally friendly energy sources in the hydrogen-oxygen fuel cells. Electricity can be generated by feeding hydrogen and oxygen through the sides of the fuel where they react over a catalysis inside of the reactor to produce water and electricity. The two half-cell reactions are

$$\tfrac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$$
$$H_2 \rightarrow 2H^+ + 2e^-$$

As mentioned, this fuel cell is the purest form of energy production as there are no green house gases or other products produced that are harmful to the environments (Figure 25).

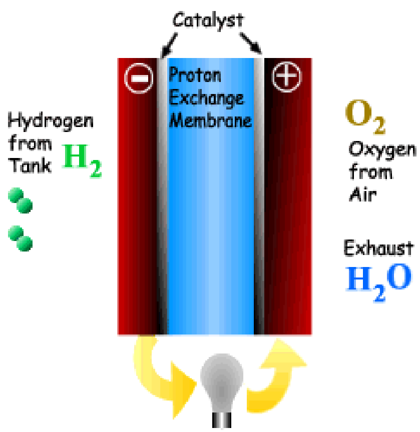


Figure 25. Hydrogen and Fuel Cells

Bio Fuels
While there are many sources of biofuels such as switch grass mentioned earlier, I would like to close with a project that I have been associated with. This process is to grow and process algae to make algae fuel oil. Figure 26 shows green algae growing on a pond.

Figure 26. Algae as a Biofuel

Algae are commercially grown in "raceway" ponds (reactors) as shown in Figure 27. When supplied with CO_2 and sunlight, algae grow and divide to produce more algae.

$$\text{Sunlight} + CO_2 + H_2O + \text{Algae} \rightarrow \text{More Algae} + O_2$$

The carbon dioxide feed to the algae pond can come directly from a coal or other fossil fuel combustion process and piped into the algae pond to saturate the water with CO_2. The growth rate is proportion to the amount of sunlight, the dissolved CO_2 concentration, and algae concentration.

$$\text{Growth Rate} = \text{Sunlight} * \mu * C_{\text{Cells}}$$

$$\text{where} \quad \mu = \frac{\mu_0 C_{CO_2}}{K_m + C_{CO_2}}$$

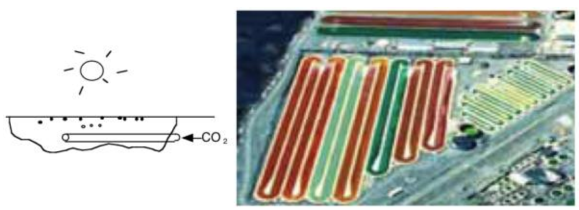


Figure 27. Biofuels: Raceway Ponds to Grow Algae

Research and pilot plants are already in operation to rapidly grow and convert algae to fuel oil. The algae are harvested from the pond, concentrated using flocculating agents and then placed in a high temperature extractor where they are processed and reacted to form algae fuel oil. One such reactor and the corresponding reactor system are shown in Figure 28.

Figure 28. Algae is processed to extract oil and nutrients

<u>What To Do?</u>
Table 2 gives a summary of the types of solar energy that chemical engineers are ideally trained to do research on in order to advance the field. As faculty, our job is to teach and guide these students to develop critical and creative thinking skills so that they can move the energy field forward.

Table 2

For Students and Practicing Engineers to Focus on	
Solar Thermal:	Nanoparticles for Energy Capture
Solar Thermal:	CSP Biofuels and Reactor Design
Solar Voltaic:	New Materials for Surface Design
Solar Chemical:	New Chemicals and Reactor Design
Photo catalysis:	New Materials and Reactor Design
Fuel Cells:	New Membrane Materials
Biomass:	Determining the Best Fuel Sources
For Faculty to Focus on	
Developing Students Critical and Creative Thinking Skills	

You will note in Table 2 that I have added a challenge to faculty. That is, in addition to teaching the fundamental technical content and carrying out research in core areas, faculty need to develop problems, exercises and courses to increase the students' critical and creating thinking skills. The chemical engineering department at Universitat Rovira i Virgili is doing just that!!

In closing I want to say again how thrilled and deeply honored I am to receive the *doctor honoris causa* from Universitat Rovira i Virgili. Thank you very much.

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