

EVALUATION OF SOME RENEWABLE ENERGY TECHNOLOGIES

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ОЦІНКА ДЕЯКИХ ТЕХНОЛОГІЙ ВИРОБНИЦТВА ВІДНОВЛЮВАЛЬНОЇ ЕНЕРГЕТИКИ

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ABSTRACT

Purpose. The study aims to outline and compare various renewable energy alternatives in view of the global warming crisis and depletion of fossil fuels which cause emissions of carbon dioxide. Carbon dioxide is a major source of pollution and is an absorbent for radiation.

Methods. Literature surveys and analysis of benefits and drawbacks of the competing technologies should include the capital costs, running costs and carbon footprint. Liquid fuels have high energy to weight ratio compare to say solar panels or thermal absorbers, but what is neglected is the large refinery and other processing machinery behind the liquid fuel which is adding to the carbon footprint.

Findings. Producer gas and bacterial engines are suggested as possible pollution reducing and cost effective methods for power generation. Coal, biomass, geothermal and hydroelectric have the lowest running cost, but carbon footprint cost is neglected. Solar chimneys, with low mechanical efficiency have low running costs, and no pollution. Modification of internal combustion engines to use producer gas and alcohol may reduce overall carbon footprint.

Originality. Many researches focus on energy and mechanical efficiency. Bacterial engines have yet to be fully developed, and these are wonderful chemical factories but not understood in terms of classical thermodynamics. For all technologies, return on investment is more appropriate since capital costs are also included, which are neglected in mechanical efficiency calculations.

Practical implications. Depletion of forest cover which acts as a greenhouse gas sink contributes to global warming. Worldwide, million of cars with internal combustion engines consuming petroleum, if converted to alternative fuels, can help in reducing the carbon gas emissions and ultimately to a slowdown in the global warming rate.

Keywords: *producer gas, biogas, global warming, carbon footprint, efficiency*

1. INTRODUCTION

Natural sources of power such as the use of wind, solar heating and drying, and hydropower have been commonplace in many countries for centuries. It is only in the past decade or two that the global concern has mounted with concerns for the global environment and the future of the planet, with unfortunate visible effects on the atmosphere and effects on climate worldwide. An example is the shrinking of glaciers worldwide, the shrinking of the polar icecaps and rising sea levels, resulting in worldwide calamities like tsunamis, earthquakes and cyclones. These considerations and aspects have recently been incorporated into the national plans of many countries; many global organiza-

tions and Non-Governmental Organizations (NGO) have also got into the picture. It is now common to talk about carbon credits and monetary equivalents that can be traded and used to offset production of pollutants by nations.

According to a recent study (Carey, 2012), CO₂ increase due to deforestation accounts for more CO₂ than all vehicles worldwide. Four wheelers produce 14% of the global carbon emissions, while upward of 15% is from deforestation. According to the Environmental Defense Fund (EDF), 32 million tons of tropical rain forests were cut down each year from 2000 – 2009. Forest clearing will put another 200 billion tons of carbon monoxide in the air in coming decades.

Natural organic fuels are a major power source for developing nations. Biomass continues as a source of cheap and polluting energy in rural areas, especially for below poverty line populations. The scarcity of urban dwelling spaces also forces many people to occupy fringe forest areas or collect biomass illegally from forests and destroy green cover in urban spaces. On the other hand, many people migrate to the large urban centers hoping to find work, occupying slums. The strain on the civic amenities due to the extra settlements on pavements and established slums causes problems like power outages, water shortage and epidemics. The problem of urban waste management is a difficult one. In addition, as it is now noticed, air pollution in the form of carbon emissions and methane cause global warming by the greenhouse effect.

Profits from timber, charcoal, pasture and cropland induce people to cut down forests because of easy availability and low cost. The United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation (UN-REDD Programme) provides incentives to people who care for forests and manage sustainably while still being able to benefit economically through a system of pollution credits. Brazil adopted REDD and slowed deforestation 40% since 2008 and is on the way to 80% reduction by 2020. India is not a member, though Bangladesh, Nepal, Sri Lanka, Pakistan, Myanmar have joined. Brazil is a major player in the sustainable development field, having already introduced biofuels and ethyl alcohol as motor fuel.

Pollution figures for India indicate 3000 lb/capita in 2007, China at 10500 lb/capita, and US at 42500 lb/capita. India has the worst air pollution record in the world due to the large number of two wheelers and retrofitted compressed natural gas (CNG) kits causing 30% more methane emissions together with emission from coal burning power plants.

It is well known that poverty and the degradation of the environment are closely linked, hence improvement of living standards and natural resource management at the grass roots level is essential in any strategy to reclaim the environment. The poor rely heavily on natural resources.

In addition, diversion of common lands used historically for other public projects and schemes deprives the poor of their common resources, forcing them to encroach on forest land. The dominant sources of pollution in India are domestic burning and two stroke emissions (De Laat, de Gouw, Lelieveld, & Hansel, 2001).

2012 was to be the International Year of Sustainable Energy for all, according to the UN. The climate food agricultural linkage is emphasized in relation to fossil fuel inputs. For a country like India which has a sizeable rural population subsisting on agriculture and depending on livestock, biogas has provided a viable source of energy and has been subsidized by various Governmental incentives and schemes. The problem underlying such efforts is the extreme poverty in which the majority of the rural populace lives. In fact, traditional village lifestyles dictate the use of cow dung for cooking with fire, smearing cow dung solution on the ground, placing cow dung cakes on the walls and so on. Till recently it was difficult to get people to use cow dung as a crop fertilizer, and the major fertilizer companies have made hay of this fact.

Biogas has certain desirable qualities with regard to the environment:

- it is low cost and low tech and requires low investment and capital;
- uses waste products and does not require chemical additives;
- produces a sludge which can be used further as a fertilizer;
- it can contribute to treatment of domestic and municipal wastes.

Most of the subsidies given by State and Non-Governmental Organizations (NGO) so far have been on biogas, whereas producer gas has been neglected in the resurgence of renewable energy sources.

Apart from the payoffs in secondary energy generation (i.e., after methane has been recovered from biomass by bacterial action), the remaining bio matter/biomass residue which consists of C and N with H₂O is capable of further reduction into “producer gas”. A further advantage is in reducing the biologically active component which may consist of any harmful bacteria, mosquito larvae and viruses and other vectors into inert form. The resultant solid matter is highly concentrated with nitrogenous matter and thus suitable as fertilizer for agricultural usage. Although the initial biomatter which may be dung, composted material and waste food matter can be used and is frequently applied directly on the fields, the result of producer gas reduction is more inert and as useful if not more suitable as a fertilizer. Besides, the decomposition of animal dung in the open after being applied as a surface additive for crops yields large amounts of methane and adds to the pollutants in the atmosphere, besides contributing to vector propagation like flies and mosquitoes.

In Ghana, West Africa, one of the main reasons of development of biogas is to treat sewage which is largely untreated and run off into the bush outside the villages, in order to improve sanitation and reduce attendant risks of epidemics and diseases endemic to Africa (Bensah & Brew-Hammond, 2008).

2. INTERNATIONAL EFFORTS IN THE AREA OF RENEWABLE ENERGY

Serious efforts have been made in the island nations of the Indian and Pacific Oceans, like the Philippines and Sri Lanka, subsidized by the International agencies like UN. In Africa, countries like Ghana have taken up biogas projects at a national level in their National Strategic Planning. According to a recent survey (Bensah & Brew-Hammond, 2008), the focus in Ghana has shifted from energy to sanitation, with construction of bio-toilets. The aim is to treat human wastes to a level where they can be safely discharged into drains. The remaining sludge is used as fertilizer.

In the Philippines, GEMCOR had set up gasifiers using coconut shell charcoal, resulting in cheap gas at lower rates than from wood or biomass. Boats have been fitted with engines running on producer gas (Mahin, 1983).

A number of raw materials have been researched for producer gas, including coconut, sugar cane bagasse, rice husks, corn cobs, coffee bean husks, peanut shells, cotton gin trash and stalks. The list could use organic trash, which has been reported in the recent

issue of Scientific American (Wald, 2010). Third world cities with their large slums and attendant sanitation problems could take a leaf from these efforts initiated by India's neighbors.

During times of petrol scarcity as in the last world war, engines were developed to run on coal gas and gas from wood, which would be towed behind the vehicles. A survey was done by the Food and Agriculture Organization of the United Nations (FAO of the UN) in the 1970's and the results were published as a paper (Wood Gas as Engine Fuel, 1986).

Photovoltaic energy has also been looked at in detail in the context of agricultural and rural development. The life cycle and quality factors for such sources have been estimated (Campen, Guidi, & Best, 2000).

3. PRIMARY REACTIONS AND PRODUCTS FROM BIOMASS GASIFICATION

3.1. Basic data

The gaseous products from carbon biomass are CO, CO₂, H₂, CH₄, N₂, H₂O. Trace amounts of higher hydrocarbons are present also. Schematic of gasification process is presented in Figure 1.

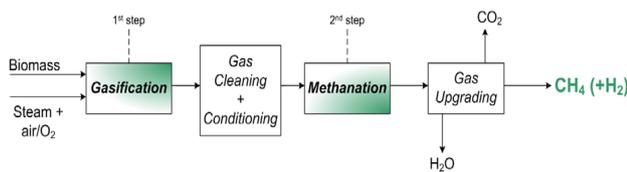


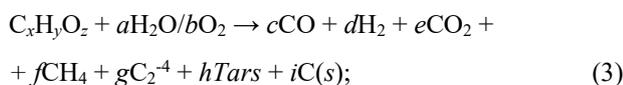
Figure 1. Schematic of gasification process

The basic reactions involve the steam reaction on carbon with limited oxygen:



Also there are sub reactions of C with H, H₂ and H₂, similarly with CO and H:

– pyrolysis/gasification:



– carbon gasification:



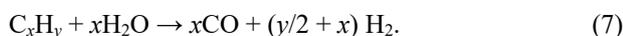
– methanation:



– water-gas shift:



– steam reforming:



These reactions need the addition of heat which is supplied by burning additional raw material, and a supply of steam.

3.2. Use in engines

Strong interests in the petroleum and automotive industry have resisted and thwarted attempts to develop alternative designs and implementation of these in industry. However, modification of engines to use producer gas is not difficult, provided one understands the nature of the combustion and power cycle in the internal combustion engine. Basically, one cannot run the engine at a speed beyond the rate at which the fuel gas ignites and burns (flame velocity). In addition, the compression and air/fuel ratio are important. If too high a compression results, there is possibility of the gas igniting spontaneously, (knocking), which would damage the engine. Producer gas is capable of higher octane numbers than petrol, (octane number being a measure of the compression ratio at which detonation occurs). As a result, higher engine thermal efficiencies can be achieved with producer gas. Further refinements are possible but may need more research. One such possibility is to use regeneration and reheat as in the Rankine cycle.

Some studies have appeared on the use of producer gas in IC engines of 1000 KW capacity (Sridhar et al., 2005).

3.3. Producer gas for power generation

1 kg air-dry wood (15 – 20% mc) gives about 2.3 m³ of gas; 1 litre petrol = 2.5 to 3 kg wood; 1 litre diesel = 3 to 3.5 kg wood; 1 kWh requires 1 to 1.3 kg charcoal, 2 to 4 kg woodchips or 2.4 to 3.2 kg rice husk.

Feasibility and viability of a gasifier project depends on many factors, including cost of fuel, labour costs, money and finance, design life, value of the energy produced, cost of disposal of the residue, and value of the sludge for fertilizer. Further benefits are there when the electricity if generated can be sold to the grid.

The existence of a national energy programme and incorporation of such schemes into the development plans at state and national level would enhance such energy schemes.

At present the focus has been blurred by the large corporations battling it out for offshore oil rights, trying to sell cheap gas guzzling cars to the public, the conflicts (oil generated) in the middle east, and other political agendas. The attendant benefits of health and sanitation have been almost ignored in the energy plans at the higher levels.

In Tanzania, a programme for design of gasifiers for maize mills in rural areas was taken up by the Small Industries Development Organisation and the Netherlands Twente University (Mahin, 1983). A similar system was developed at Chulalongkorn University in Thailand. In El Salvador, with GEKA of Karlsruhe, coffee bean husks are burnt and the gas mixture fed to further dry coffee beans. In Valdosta, Georgia and Auburn, Alabama peanut shells have been used to give heat for drying. In Asia, rice husks are very commonly available as a by-product, but according to the FAO in 1975, no mill existed which used steam produced by husk fired boilers. India and Thailand directly used rice husks as a form of boiler heat fuel, with some other countries also following suit. Parboiled rice in India is made mostly (50% usage) by husk fired boilers, with some mills in Sri Lanka, Guyana, and Italy doing the same. The Govt of Malaysia had given funds for development of two pilot

plants at rice mills using one ton of rice husks per hour. Electric power output of about 350 KW/hour has been obtained in 1983 (Mahin, 1983).

3.4. Drawbacks of producer and syngas

Many engines and gas turbines being used for power generation are now using syngas and producer gas. It appears that while natural gas has 3% water content, syngas has about 18% water content which creates degradation and corrosion problems in the metal parts of these engines.

3.5. Overall efficiency and economic analysis of the scheme

Since producer gas production requires heat and steam production as input, there is an expenditure of energy involved which debits from the overall total of energy. The heating can be obtained by diverting part of the biogas obtained in the primary digestion stage to be used for heating and producing steam and high temperatures in gasifying the sludge residue for Producer gas. Alternatively, dried biomass used for the initial biogas production could be ignited and used for the secondary producer gas stage. So far, no study has been done on the efficiency and economics of the scheme. Producer gas was used to run a modified internal combustion engine (Sridhar et al., 2005), with reasonable results.

3.6. Improvement of efficiency by cogeneration and regeneration

Basically, the work done is the area under the P – V curve, so any increase in the area implies an increase in the work obtainable within the input and output temperatures. Figure 2 shows the effect of regeneration, (applying some exhaust heat to heat the incoming fluid before the main cycle), similar to the Rankine cycle principle used commonly in the steam turbine technology.

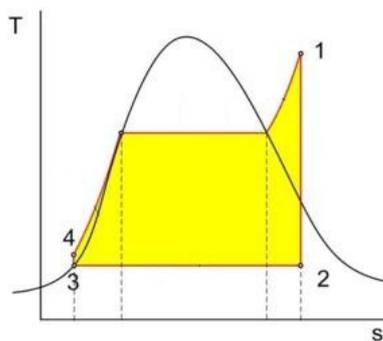


Figure 2. Increase of working area under P – V curve for Rankine cycle

3.7. Improvements by hybridisation

A combination of gasification and solid fuel cell was examined by F.P. Nagel (2008) where solid oxide fuel cell (SOFC) was operated with producer gas.

A comparison of various SOFC schemes is given in the Table 1.

It was claimed that compared to methane, dilution of producer gas reduced the output of the SOFC (Fig. 3).

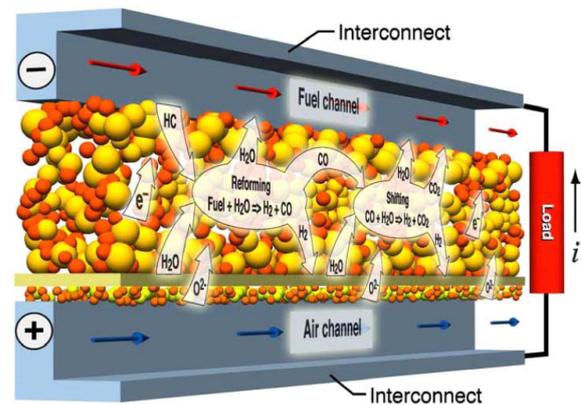


Figure 3. Working principle of an internally reforming anode supported SOFC (Nagel, 2008)

4. IMPROVEMENTS BY USING STIRLING AND BRAYTON CYCLES

It can be demonstrated that theoretical efficiency of the Stirling and Brayton cycles is the same as the Carnot efficiency and hence any power generator based on these cycles must have the highest efficiencies. Stirling was one of the first engines used during the industrial revolution, predating the internal combustion engine, and could use any type of fuel as it was externally heated. It is now making a comeback, especially amongst submarine applications for its silent operation, and in space application for low temperature differential engines (NASA). The same considerations of improvement of efficiency by regeneration apply here, and an important part of any Stirling engine is the regenerator and heat exchanger. By contrast, the Solar chimney has one of the lowest over all efficiencies, in terms of the conversion of incident solar energy. It has however been attempted in a number of countries, and a few references are given for illustration. Spain was one of the first countries to apply the technology (Santos Bernardes, 2010), after which Algeria, Egypt, Jordan have also attempted the technology with pilot plants. The drawback for the Solar chimney is high capital cost. A recent attempt using a flexible floating chimney has been reported from Greece, which claims to avoid wind loads (Christos, 2010) (Fig. 4). Data from studies show that the overall efficiency of the chimney is around 1% (i.e. of the incoming solar energy, 1% is converted to usable energy).

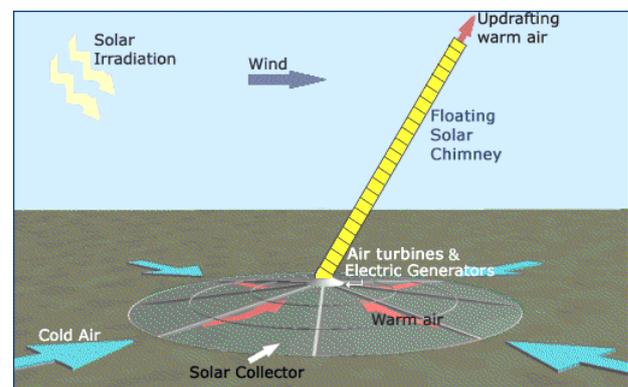
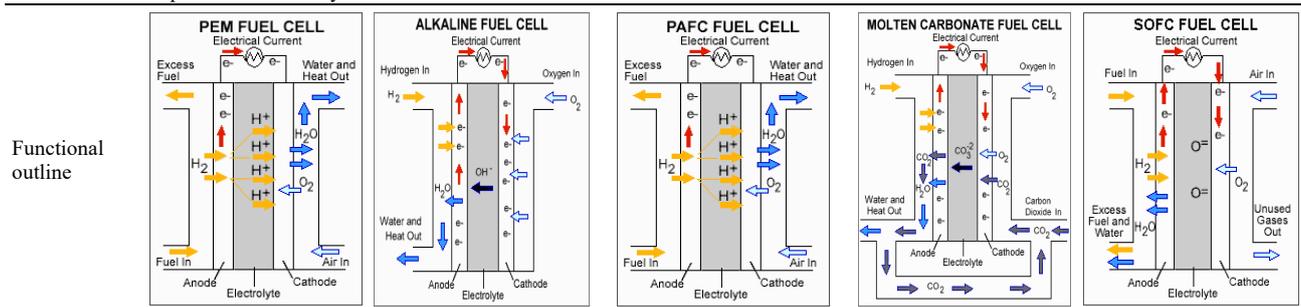


Figure 4. Floating solar chimney (Christos, 2010)

Table 1. Schematic of gasification process (comparison of various schemes) (Nagel, 2008)

FC Type	Low temperature FC		Mid temperature FC	High temperature FC	
	PEMFC	AFC	PAFC	MCFC	SOFC
Electrolyte	Solid organic polymer polyperfluorosulfonic acid	Aqueous solution of potassium hydroxide soaked in a matrix	Liquid phosphoric acid soaked in a matrix	Liquid solution of lithium, sodium and/or potassium carbonates soaked in a matrix	Solid yttrium stabilized zirconium oxide
Oxidant – cathode gas	Oxygen or air	Pure oxygen	Air	Air	Air
Cathode reaction	$2H^+ + 2e^- + 0.5O_2 \rightarrow H_2O$	$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$	$2H^+ + 2e^- + 0.5O_2 \rightarrow H_2O$	$0.5O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$	$0.5O_2 + 2e^- \rightarrow O^{2-}$
Fuel – anode gas	Hydrogen	Pure hydrogen	Hydrogen	Hydrogen, carbon monoxide, methane	Hydrogen, carbon monoxide, methane
Anode reaction	$H_2 \rightarrow 2H^+ + 2e^-$	$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$	$H_2 \rightarrow 2H^+ + 2e^-$	$H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$ $CO + CO_3^{2-} \rightarrow 2CO_2 + 2e^-$ $CH_4 + 4CO_3^{2-} \rightarrow 5CO_2 + 2H_2O + 8e^-$	$H^2 + O^{2-} \rightarrow H_2O + 2e^-$ $CO + O^{2-} \rightarrow CO_2 + 2e^-$ $CH_4 + 4O^{2-} \rightarrow CO_2 + 2H_2O + 8e^-$
Overall reaction	$H_2 + 0.5O_2 \rightarrow H_2O$	$2H_2 + O_2 \rightarrow 2H_2O$	$H_2 + 0.5O_2 \rightarrow H_2O$	$H_2 + 0.5O_2 \rightarrow H_2O$ $CO + 0.5O_2 \rightarrow CO_2$ $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	$H_2 + 0.5O_2 \rightarrow H_2O$ $CO + 0.5O_2 \rightarrow CO_2$ $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
Fuel requirements	CO < 10 – 100 ppmV	Pure hydrogen needed	CO < 1 vol. % N ₂ < 4 vol. %	—	—
Operating temperature	50 – 90°C	50 – 90°C	160 – 220°C	600 – 660°C	700 – 1000°C
Electrical efficiency	35 – 60%	50 – 79%	35 – 50%	40 – 55%	45 – 60%
Applications	Mobile, stationary power generation	Military, space	CHP-generation	CHP-generation	CHP-generation, additional power units
Advantages	<ul style="list-style-type: none"> – quick start-up due to low temperature; – favorable power-to-weight ratio; – low sensitivity to orientation 	<ul style="list-style-type: none"> – high performance due to fast cathode reaction; – variety of non-precious catalysts; – high efficiencies 	<ul style="list-style-type: none"> – most mature cell type; – CHP-generation possible; – less fuel impurity sensitive 	<ul style="list-style-type: none"> – high efficiency; – CHP-generation possible; – fuel flexibility due to int. reforming; – non-precious metal catalysts 	<ul style="list-style-type: none"> – plate and tube-like configurations; – high efficiency and fuel flexibility; – non-precious metal catalysts; – most sulfur-resistant FC
Disadvantages	<ul style="list-style-type: none"> – expensive catalysts required; – prone to carbon monoxide poisoning; – hydrogen storage or onboard fuel processor necessary 	<ul style="list-style-type: none"> – pure fuel and oxidant required; – prone to carbon dioxide poisoning 	<ul style="list-style-type: none"> – low efficiency to other FCs; – requires Pt-catalyst; – large size and weight 	<ul style="list-style-type: none"> – corrosive electrolyte; – accelerated breakdown of cell components due to high temperature 	<ul style="list-style-type: none"> – slow start-up; – necessity of thermal shielding; – accelerated breakdown of cell components due to high temperature



The chimney efficiency is:

$$\eta = \frac{h}{C_p(T_2 - T_1)}, \quad (8)$$

and since the Carnot efficiency is $(T_2 - T_1)/T_2$, the resultant efficiency becomes $h/(C_p T_1)$,

where:

- C_p – specific heat;
- h – height of air column;
- T_2 – working temperature;
- T_1 – ambient temperature (sink);
- η – efficiency.

Coupled with other losses, the efficiency is less than 1% in practice. One may also look at the “economic efficiency”, i.e. the internal rate of return for payback.

According to Al-Dabbas (Al-Dabbas, 2011), an area of 46000 m² can yield 50 KW. At incident solar energy of 1 KW/sqm, this gives an efficiency of 1%, and at peak incidence of 5 KW/sqm, efficiency of 0.02%. Also, costs of maintenance and salaries would go up geometrically, increasing the estimates given. The extreme desert cold at night however will require thermal mass to offset it and allow for fast startup during the day, which is not mentioned. Estimates depending on the interest rate show

amortization for 25 – 40 years with high per unit costs compared to existing technologies (Al-Dabbas, 2011). For 40 years’ time, the cost per KWh is 0.25 to 0.40 Euro for amortizations of 6 to 10% (Fig. 5).

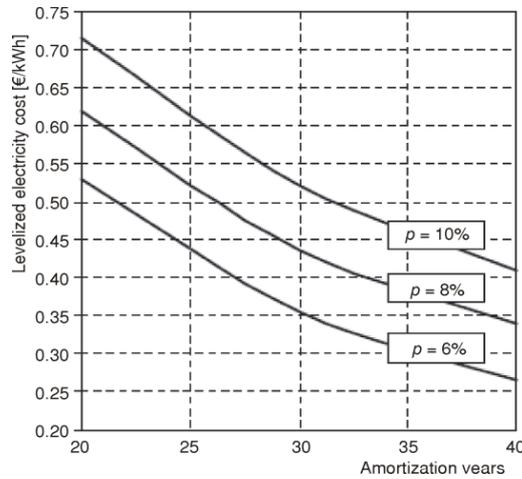


Figure 5. Influence of amortization on unit cost (Al-Dabbas, 2011)

A comparison of various technologies from (Christos, 2010) is given below in Table 2.

Table 2. A cost comparison of electricity generating technologies

MWh direct production cost in EURO	Fuel or method of electricity generation	Investment in EURO per produced MWh/year	Mode of operation and capacity factor
55 – 60	Coal fired (not including carbon emission penalties)	200	Combined cycle base load 85%
80 – 100	Coal fired with CCS (carbon capture and storage)	300 – 400	Combined cycle base load 85%
60 – 65	Natural gas fired (not including carbon emission penalties)	150	Combined cycle 85%
65 – 75	Nuclear fission	400 – 450	Base load 95%
60	Wind parks onshore	500	Intermittent 30%
75	Wind parks offshore	650	Intermittent 30%
180	Concentrating Solar CSP	2000	Continuous with thermal storage 30%
280	Photo voltaic PV	3000	Intermittent 15 – 17%
155	Solar chimney concrete	~2000	Continuous ~50%
~60	Floating solar chimney	~500	Continuous ~50%
55 – 75	Biomass	500 – 700	Continuous 85%
50 – 70	Geothermal	500 – 800	Continuous 90% (limited resource)
50 – 60	Hydroelectric	500 – 800	Continuous (load following, limited resource)

4.1. Self-gasification from biomass

Biomass self-gasification has been reported by Van Rossum (Rossum, Nanou, Swaaij, & Kersten, 2013), where the heat released by methanation is applied for the heat required for gasification. Exxon is reported to have used it in the 80’s, in high pressure coal gasification. Full syngas cycle of biomass self-gasification is presented in Figure 6.

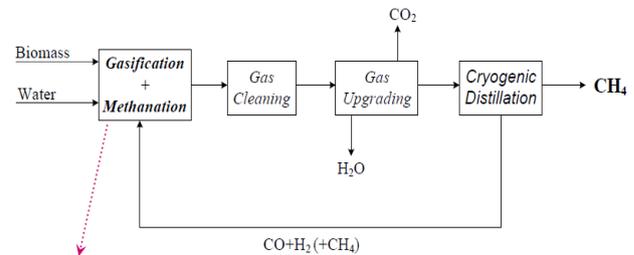


Figure 6. Full syngas cycle

J.D. Mackaluso (2007) has described bio catalysts for producing syngas which then can be processed into alcohol for fuel. The advantage is in using waste which would otherwise be dumped into the ocean or landfills.

5. FUTURE STUDIES AND AVENUES OF RESEARCH

It may be possible to invoke the genetic modification of microbes to directly excrete hydrocarbons. Turning water, photonic energy and carbon dioxide into hydrocarbons is a very old process developed by nature, which uses chlorophyll. Perhaps more useful than solid carbohydrates, would be a liquid hydrocarbon that could directly be put to use as fuel. Algae are known to efficiently convert carbon dioxide into fatty acids, and similarly potato plants into carbohydrates. Converting this potato starch into alcohol is a long and expensive process. There has been a search for microorganisms that could do this (Ethanol Fermentation, 2017). Alternatively, sugars can be turned into alcohol, but again there are attendant costs. Much more attractive and useful would be a way to convert raw materials directly into hydrocarbon fuels. Apart from microorganisms, mobile robots are being proposed that would “eat” garbage and unwanted plants and convert these into hydrocarbon fuel forms (Pavlus, 2010).

The direct conversion of cellulose to alcohol (cellulolysis) using lignocellulose (wood cellulose containing lignin a component of wood), has been researched at Argonne Labs (The Bioenergy Technologies Office..., 2017). The process depends on cellulase enzymes produced by bacteria. *Saccharomyces cerevisiae*, *Zymomonas mobilis*, *E. Coli*, are some bacteria targeted for bio engineering to produce ethanol via the cellulosis route. One way to obtain hydrogen from syngas is through the use of the bacterium *Rhodospirillum rubrum*. *Rhodospirillum rubrum* is a photosynthetic proteo-bacterium that converts syngas to hydrogen through a process known as the water gas shift reaction (Najafpour, Younesi, & Mohamed, 2004; Younesi, Najafpour, Ku Ismail, Mohamed, & Kamaruddin, 2008) have performed multiple experiments to test the ability of *Rhodospirillum rubrum* to convert syngas.

Producer gas has been applied as a raw material for bacterial conversion to ethanol also, using the bacteria *Clostridium Ljungdahlii*, which ingests CO, CO₂ and H₂ producing ethanol and water. This process involves gasification, fermentation and distillation to yield alcohol. The alternative is to use a catalytic reactor. Catalysis involves intermediate compounds that get involved in the reaction but are unchanged in composition at the end.

The physical and chemical parameters affecting fermentation of cellulose has been studied by various groups (Armstrong & Martin, 1983; Senthilkumar & Gunasekaran, 2005). Another bacteria *acetivibro cellulolyticus* produces acetate, ethanol, water and carbon dioxide.

Recently, groups have tried to bioengineer bacteria to give oil for fuel directly. The group LS9 with UC Berkeley has engineered a bacterium to make enzymes to convert biomass into diesel oil (Bourzac, 2010). A recent US Patent No. 7794969 uses cyanobacteria to produce n-alkanes (Reppas & Ridley, 2010).

The end is not in sight, and clearly microorganisms exist or can be modified to excrete oils which can be used as fuels, possible without further processing. However, the overall effect on the effect on life on the planet and the ecology and environment must be carefully evaluated before attempting such bioengineering on a large scale in order to satiate the need of some industrial groups which have stuck to old designs for motive engines. The alternative would be to invest in alternative designs for motive power converters.

The internal combustion engine was a byproduct of the Industrial revolution and the industrialization of the Midwest USA, with resultant mass migrations, prior to which electric cars, steam cars and other variants were in vogue in the early 20th century. In fact, the steam engine served Indian railroads for well over a century before the diesel engines took over. Hence one must not get carried away by the demons of science and finance and attempt to change the natural order of nature and life by introducing artificial genetic alterations.

In order to maintain sustainable development in consonance with International efforts and agreed norms, it is essential that efforts to reengineer life forms, regardless of good motives be examined carefully as there can be repercussions in the long run.

In conclusion an ongoing debate is raging amongst various international pundits. It is about the pros and cons of the link between pollution and economic growth. It was suggested in a nutshell, that economic growth alone would take care of the environment after a certain level of prosperity was reached. The idea is a fall out of the Environmental Kuznets Curve (EKC). It is also recognized that depletion of resources from LDC's is an important effect because It is rare for natural resources and capital obtained in this way by pirating resources of LDC's by more developed countries to be reinvested in a sustainable way (Grossman & Krueger, 1991; Barbier, 1997). It is perhaps one reason why the developed countries refuse to sign the Kyoto and other protocols, believing that nature will eventually take care of itself. The Kuznet's Curves for EEC, US show the downturn, but the downturn has not occurred so far for India and China.

6. FUTURE EFFORTS IN BIOTECHNOLOGY

A primary necessary step in the production of second generation biofuels is through syngas, from biomass. There are two major approaches.

The first is by fluidized bed gasification of biomass to fuel gas at approximately 900°C. This option requires almost no biomass pre-treatment, the product gas however needs downstream catalytic upgrading. Reforming the hydrocarbons to syngas is done catalytically. Such gasification technology has already been demonstrated with biomass for generating heat and/or electricity (Nizetic, Ninic, & Klarin, 2008; Kempegowda, Tran, & Skreiberg, 2011).

Second is by entrained flow gasification at high temperature to produce syngas without methane or other hydrocarbons (1000 – 1300°C), with sufficient catalytically active components like K or Na.

Flash pyrolysis: biomass is liquefied to oil/char slurry, which can be atomized in an entrained flow gasifier: the high-energy density slurry can also be transported and processed at a central facility.

Torrefaction: biomass is thermally treated at 250 – 300°C to produce brittle and pulverizable fuel. This can be done on the site, but also before transporting the solid fuel. The latter is attractive since torrefied biomass pulverizes easily; subsequent pelletisation consumes relatively little energy. The torrefied biomass pellet has a high energy density and thus offers economic gains in transportation. Biomass is converted at 600 – 900°C into gas, with significant amounts of small char particles entrained with it. The mixture is directed to the high temperature entrained flow gasifier to convert it to syngas. This combination has a very high efficiency and allows the feeding of conventional chips.

Other schemes could be developed integrating these concepts to produce bio-syngas. From bio-syngas one can synthesize different types of biofuels like Fischer-Tropsch fuels, methanol, DME, mixed alcohols, including pure hydrogen. Extensive gas cleaning and conditioning is required in all these applications.

In one process (Henstra, Sipma, Rinzema, & Stams, 2007), waste products and various feedstocks convert into syngas. Then, the bacterium *Clostridium Ljungdahlii* is exposed to syngas and performs fermentation producing ethanol in the process. The ethanol is then extracted by distillation of the mixture. In addition to producing ethanol, BRI plants also generate electricity. Prior to applying *Clostridium Ljungdahlii*, cooling of the syngas is required; and, heat released during cooling is used to generate electricity. It is claimed that up to 85 gallons of ethanol for every ton of biomass and up to 150 gallons for every ton of hydrocarbon-rich material are converted (Henstra, Sipma, Rinzema, & Stams, 2007). Another less known area of current interest in the field of renewable energy, is wave energy harvested from ocean currents and waves (Uihlein & Magagna, 2016).

7. CONCLUSIONS

Apart from nuclear energy, the alternative energy technologies all derive from solar energy, and in a sense even fossil fuels are derived from archaic biomass produced by solar energy. It is seen that inefficient conver-

sion technologies like the solar chimney can produce sufficient power provided sufficient infrastructure and capital expenditure is applied. However, developing large amounts of capital assets and infrastructure involves producing large amounts of energy, in terms of the carbon footprint, which will take longer to recover, apart from recovery of capital. The other technologies that use readily available biomass and fossil fuel require lower capital asset development and perhaps lower technology and energy expenditure in manufacture of engines and generating stations. The total energy budget and outlay needs to be looked at and the payback assessed over the life of the generator, along with capital payback to get a fair and full estimate of the relative merits amongst the various alternatives. Solar chimneys are the lowest efficiency alternatives; however, the input energy is free and inexhaustible. On the other hand, the Stirling and Brayton engines have the highest thermodynamic (Carnot) efficiencies, yet have not been developed to the extent of the Diesel and two stroke Internal combustion engines which are among the major polluting sources today. An alternative efficiency (internal rate of return), or economic efficiency, may also be considered.

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ABSTRACT (IN UKRAINIAN)

Мета. Надати і порівняти різні види відновлюваної енергії з урахуванням енергетичної кризи, пов'язаної з глобальним потеплінням і виснаженням викопних джерел палива, що призводить до викидів вуглекислого газу, який є головним джерелом забруднення атмосфери й поглинання радіації.

Методика. При огляді літературних джерел та аналізі переваг і недоліків конкуруючих технологій необхідно враховувати капітальні й експлуатаційні витрати, а також вуглецевий слід. Рідкі види палива відрізняються більш високою питомою енергією по масі в порівнянні з сонячними панелями або термокомпенсаторами. Не можна недооцінювати той факт, що виробництво рідкого палива передбачає наявність громіздкого очисного й переробного обладнання, робота якого збільшує вуглецевий слід.

Результати. Генераторний газ і бактеріальні двигуни пропонуються в якості способу зменшення забруднення та економічного отримання електричної енергії. Отримання електроенергії на геотермальних і гідроелектростанціях, а також на станціях, що працюють на вугіллі чи біомасі, передбачає низькі витрати на експлуатацію. Однак, при цьому не враховуються витрати на боротьбу з вуглецевими викидами. Сонячні електростанції аеродинамічного типу при малому механічному ККД відрізняються низькими експлуатаційними витратами і практично не забруднюють навколишнє середовище. Модифіковані двигуни внутрішнього згорання, що дозволяють отримувати генераторний газ і спирт, можуть сприяти зменшенню вуглецевих викидів.

Наукова новизна. Багато вчених розглядають проблеми отримання енергії й підвищення механічного ККД. Необхідно вдосконалювати бактеріальні двигуни, свого роду хімічні фабрики, робота яких ще не до кінця зрозуміла з точки зору класичної термодинаміки. Оцінюючи різні технології, слід виходити з окупності інвестицій, оскільки вона включає капітальні витрати, які зазвичай не враховуються при розрахунках механічного ККД.

Практична значимість. Скорочення лісового покриву планети, який є поглиначем парникових газів, призводить до глобального потепління. Якщо двигуни мільйонів машин по всьому світу перевести з бензину на альтернативні види палива, скоротяться парникові викиди й сповільняться темпи глобального потепління.

Ключові слова: генераторний газ, біогаз, глобальне потепління, вуглецевий слід, ККД

ABSTRACT (IN RUSSIAN)

Цель. Представить и сравнить различные виды возобновляемой энергии с учетом энергетического кризиса, связанного с глобальным потеплением и истощением ископаемых источников топлива, что приводит к выбросам углекислого газа, который является главным источником загрязнения атмосферы и поглощения радиации.

Методика. При обзоре литературных источников и анализе преимуществ и недостатков конкурирующих технологий необходимо учитывать капитальные и эксплуатационные затраты, а также углеродный след. Жидкие виды топлива отличаются более высокой удельной энергией по массе по сравнению с солнечными панелями или термокомпенсаторами. Нельзя недооценивать тот факт, что производство жидкого топлива предполагает наличие громоздкого очистного и перерабатывающего оборудования, работа которого увеличивает углеродный след.

Результаты. Генераторный газ и бактериальные двигатели предлагаются в качестве способа уменьшения загрязнения и экономичного получения электрической энергии. Получение электроэнергии на геотермальных и гидроэлектростанциях, а также на станциях, работающих на угле или биомассе, предполагает низкие расходы на эксплуатацию. Однако, при этом не учитываются расходы на борьбу с углеродистыми выбросами. Солнечные электростанции аэродинамического типа при малом механическом КПД отличаются низкими эксплуатационными расходами и практически не загрязняют окружающую среду. Модифицированные двигатели внутреннего сгорания, позволяющие получать генераторный газ и спирт, могут способствовать уменьшению углеродистых выбросов.

Научная новизна. Многие ученые рассматривают проблемы получения энергии и повышения механического КПД. Необходимо совершенствовать бактериальные двигатели, своего рода химические фабрики, работа которых еще не до конца понятна с точки зрения классической термодинамики. Оценивая различные технологии, следует исходить из окупаемости инвестиций, поскольку она включает капитальные затраты, которые обычно не учитываются при расчетах механического КПД.

Практическая значимость. Сокращение лесного покрова планеты, который является поглотителем парниковых газов, приводит к глобальному потеплению. Если двигатели миллионов машин по всему миру перевести с бензина на альтернативные виды топлива, сократятся парниковые выбросы и замедлятся темпы глобального потепления.

Ключевые слова: генераторный газ, биогаз, глобальное потепление, углеродный след, КПД

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