CHAPTER 2

ENERGY FROM BIOMASS

Doreen Lum, Louise Tom

Introduction

Organic wastes are produced all around us. Although they are still generally considered as a problem rather than a resoruce, it is inevitable that organic wastes will be used more and more as a raw material as our natural resources become depleted. Organic wastes, in the forms of refuse and sewage sludge, as well as algae grown from these wastes, all represent forms of biomass with a potential for energy production. This section will illustrate ways of recovering this energy through anaerobic digestion, incineration, and pyrolysis. The following discussions will clearly indicate that the utilization of these processes in the Bay Area requires further investigation for optimal usage in terms of economics, efficiency, and environmental effects.

METHANE GAS PRODUCTION THROUGH BY-PRODUCTS OF WASTEWATER TREATMENT

Doreen Lum

With the rising population in the Bay Area, the amount of sewage, that is, wastewater increases proportionately. The solid organic waste extracted from reclaimed water, however, is more than just waste; it is a potential energy resource since it can be converted by bacteria to methane gas. With the decreasing energy supply and our continued energy consumption, the use of organic wastes as an energy source makes very good sense and deserves investigation.

Bacterial conversion of organic matter to methane gas is a natural biological process which occurs under certain conditions: a temperature maintained at 25° and $35^{\circ}C$, pH near 7.3, the absence of oxygen (anaerobic conditions) in an enclosed environment, and substrate composition. The conversion (anaerobic digestion) is a complex biochemical process in which several groups of organisms simultaneously assimilate and break down organic matter. It is a two phase process: 1) Acid-forming bacteria convert organic matter extracted from wastewater to volatile organic acids. 2) The second phase involves conversion of the volatile organic acids by methane producing bacteria primarily to methane gas and carbon dioxide. The methane gas which results from this process has a potential for use as an alternative energy source.

Presently there are two systems to claim organic matter from wastewater. The one most widely used is the conventional wastewater treatment facility where sludge is the by-product. The other system is ponding which involves the production of algae from decomposed organic matter and sunlight. Thus, two different substrates are used; sludge and algae. The major differences are that algae is living organic matter, while sludge is composed of non-living organic matter.

Methane production from sludge

The conventional wastewater treatment facility extracts sludge. Sludge is a broad term used to describe the various aqueous suspensions of solids encountered during treatment. The nature and concentration of the solids encountered during treatment. The nature and concentration of the solids vary, however, they are principally carbon compounds and a few inorganic materials.

Following the collection of sludge it is transferred into a digester in which the bacterial conversion of organic matter is activated. The goal of the digester is not for methane production at the present, but primarily for stabilization; that is to make the sludge less odorous, to reduce the pathogenic organism content, and to decrease the amount of suspended sludge solids. Under Public Law 92-500, the wasted solids must be rendered suitable in quality so that disposal, storage, or reuse can be carried out without significant environmental hazard or nuisance.[10] The digested sludge which has gone through the digester once is then used as land fill.

In 1975, 445.4 tons of dry sludge solids per day were generated by wastewater facilities in the nine county Bay Area region.[12] The amount of sludge produced is increasing. A projection made by the San Francisco Bay Basin Plan predicts nearly 1000 tons of raw sludge per day to be extracted by the year 1985.[13] However, with the recent water conservation measures in the Bay Area, it is hoped that there will be a significant decrease in the amount of wastewater. Although a reduction of waste occurs, we still must cope with the management of sludge.

The by-product of most concern in this paper is the methane gas evolving from the stabilization process. The quality and amount of methane gas produced from the digester depends on the sludge composition, temperature, and alkalinity of the digester, all of which directly affect the activity of the bacterial conversion. In general, the heat value of sludge gas is approximately 566 BTU/cu.ft. Only about 30-35% of the raw sludge ends up as burnable gas.[5] Unfortunately, this gas is of low quality. It must be purified by the removal of carbon dioxide, bydrogen sulfide, and a few other elements. Often it is necessary to mix in a higher quality gas to upgrade the heat content. At the present, many treatment plants are using a portion of the digester gases to heat various facilities on the site, while the greater part is allowed to burn off as an useless by-product.

The net yield of methane gas available is decreased due to the energy input needed to upgrade the value of the fuel. The quantity of methane produced from the digester may seem negligible, but it can supply sufficient energy for many of the facilities on site. There is no reason why any of the methane gas produced should be allowed to go unused because of the small yield. Even a negligible amount of natural gas will be of significance, with the increasing price of energy in the future.

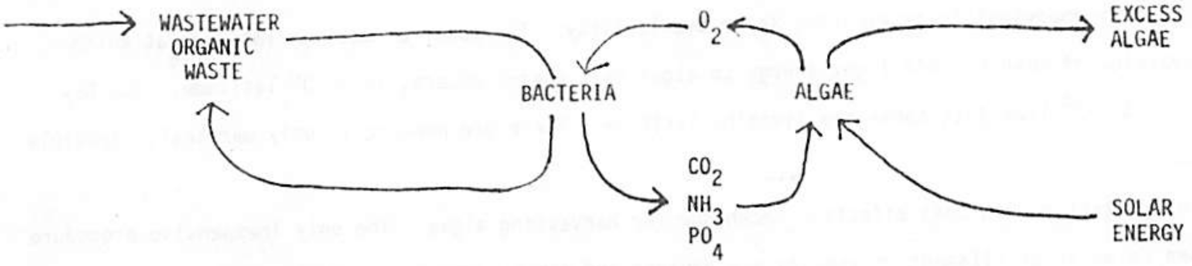
Digested sludge, the residue which remains after sludge digestion, still remains a problem for the environment. The short term solution for most Bay region wastewater treatment agencies is landfill disposal.

Further energy recovery from the digested sludge is possible through incineration, but this has many drawbacks. Since incineration requires a very dry substance, mechanical dewatering is necessary to dry the digested sludge completely. The process of mechanical dewatering requires extra energy input, and thus is very costly. At the present, the drying process is not economically feasible. Also, there is not enough heat produced in the incineration process to generate steam and eventually electricity to overcome the high cost of such an operation. Another major deterrent to the widespread usage of incineration is the difficult air quality standard it is forced to meet.[6] Until a more efficient and economical management program is introduced, disposal of the digested sludge is the only short term solution.

Continuing the disposal of digested sludge as landfill will eventually result in a severe detriment to the environment. The Bay Area local governements have been faced with the sludge dilemma for some time. At the present the San Francisco Bay Region Wastewater Solids Study is doing extensive research on potential beneficial uses of sludge. Alternative solutions under consideration include using digested sludge as fertilizer, combining sludge with garbage and other solid wastes to recover energy, and for agricultural purposes.

Ponding

Ponding is a system that is in operation today exclusively for water reclamation. There are, however, studies under way investigating the use of the algae in these ponding systems to produce energy in the form of methane gas. In this proposed system, ponding would involve a close relationship between algae and bacteria, as in the following illustration:



Microalgae grow symbiotically with bacteria in liquid organic wastes in outdoor ponds. Algal nutrients composed of inorganic substrates are provided by the bacteria, which decompose organic wastes to carbon dioxide, ammonium, phosphate and other products in forms available to algae. Algae utilize solar energy to convert the inorganic substrates to algal cell material, and also provide the necessary oxygen for bacterial decomposition of organic wastes. This represents an integrated ponding system in which the nutrients of organic wastes are used repeatedly to fix solar energy in the form of algae. In the proposed system, algae are harvested as a wet slurry which is then introduced to the anaerobic digestion pond. There, much of the carbonaceous material is converted by microorganisms to methane gas and carbon dioxide.[11] The anaerobic digestion pond carries out the same bacterial conversion as in the sludge digester, but with methane gas production as the desired end product.

The methane gas from the digestion ponds is of higher quality than the methane produced in the sludge digester. This higher grade fuel is due to the purity of the algal substrate, and, above all, the ability of microalgae to fix solar energy.

In the Bay Area, there are a few ponding systems used for water reclamation, not energy. They were initiated by Dr. W.J. Oswald, professor of Public Health and Sanitary Engineering, at the University of California, Berkeley. These ponds are located in Napa, St. Helena, and at the engineering field station in Richmond.

Feasibility

The process of using algae as a methane source through bacterial conversion has tremendous potential. The decision to undertake biological solar energy fixation and conversion as a major energy source depends upon the cost of energy produced in such systems, competing land use, and socioeconomic environmental benefits and costs derived from such systems compared with those of competitive systems.[11] Nonetheless, ponding has many positive environmental effects. It is very effective for wastewater treatment, is non-polluting and is a cyclical process where the residue accumulated is put back into the pond for further decomposition. Also, under careful long range planning, Dr. Oswald points out that ponds can provide open space, wildlife enhancement, and opportunities for recreation of a significant magnitude.[10]

Land is usually the major cost of ponds, but is often considered a recoverable cost. This recoverable cost is attributed to the substantial increase of land value used for ponds. In some cases, the land has appreciated so significantly in value during its period of use for waste management that its sale price far exceeds the original cost of land and the ponds.

Adequate solar energy is essential for the growth of algae. The greater the availability of sunlight, the greater the amount of algae produced; thus there is more solar fixation by the microalgae. Since the nutrients of organic waste fix solar energy in the form of algae, nutrients must continuously be integrated into the system for maximum algal growth.

Latitude is very important in determining solar availability. The upper or maximum latitude at which sufficient conversion of mean visible light energy to algal cell energy occurs, is 37.0^{o} latitude.[9] The Bay Area, at 37.3^{o} to 37.97^{o} lies just above the limiting latitude. Therefore ponding is only marginally feasible in the Bay Area.

There is at present no low cost effective technique for harvesting algae. The only inexpensive procedure is possible when colonial or filamentous species are present and can be removed by settling or screening. This has led to the proposal that such types of algae be selectively cultivated. The smallest microalgae are highly efficient but difficult to harvest, whereas the larger microalgae are relatively easy to harvest but somewhat less efficient.[11] What needs to be developed are new algae, whose size is the best combination of efficiency and harvest ease. Work is currently being done on finding such ideal algae at the engineering field station in Richmond. Also needed are methods of controlling the species once found, and maintaining it in a growth system indefinitely. At the present, the most efficient algae can sustain a 4% efficiency conversion of visible sunlight into energy. These algae have a heat of combustion in the range of about 5-6 kilogram calories per gram of volatile substance and can yield between 50-70% of their fixed energy in the form of methane gas.

The total cost of bio-gas from such ponds has been estimated according to data available on the cost of construction and operation of large systems. Neglecting the cost of land, such systems are expected to cost approximately $10,000 per hectare, which with amortization and interest could cost $1000 per hectare per year. For many ponding systems, operation and maintenance add an additional $1000/hectare/year to the cost. Thus, the total cost could come to a total of $2000/hectare/year. It has been estimated that at a latitude of 35^{o}, the net yield of energy produced is 550 million BTU/hectare/year. Therefore, the unit cost would be $3.64 per million BTU.[11] It must be remembered that included in this cost is the dollar value of water reclamation that has not been subtracted from the $3.64 cost of methane gas production.

A decrease in the total cost of energy from ponding can be expected with improved species and species control, more economical means of harvesting algae, improved photosynthetic efficiency, and better methods of integrating nutrients for continuous algal growth. It is essential that further research be carried out so that the full potential of methane gas from ponding can be developed. The expected cost of methane gas with these improvements will be approximately $2/million BTU.[9] Even though this rate is above the current price of gas, the expected rise in gas cost in the future may increase the attractiveness of ponding systems for methane gas production combined with wastewater treatment. Dr. Oswald believes that waste in ponds can contribute nearly 5% of the total energy usage in California.[9] Since it takes nearly 10 years to build an efficient system, it shouldbe planned now for the future.

In summary, the goal of the ponding system for methane gas production is to attain the most efficient and harvestable algae, so that a maximum yield of methane gas can be produced through anaerobic digestion. The basic requirements for reaching these standards are solar and nutrient availability, which in turn are dependent upon latitude and a continuous integration of nutrients into the system. Since latitude is an essential variable for solar availability, the Bay Area is ill-suited for such a ponding system. Geographically, the Bay Area lies above the maximum latitude for efficient conversion of visible light energy into algal cell energy.

ENERGY FROM SOLID WASTE

Louise Tom

The nine Bay Area Counties generate increasingly greater amounts of solid waste every year with increases in population, per capita consumption, the amount and variety of packaging materials, and with more stringent air and water quality standards necessitating greater removal of contaminants. In 1975, approximately 10.8 million tons of solid waste were generated, 12 million tons are estimated for 1980, and 12.9 million tons for 1990.[2]

As landfill sites become unavailable, other alternatives are becoming more viable. Municipal refuse typically has a heating value one-third that of good grade coal and is virtually free of sulfur. Through pyrolysis and incineration it could become an asset instead of being a liability to be disposed of as quickly as possible.

Pyrolysis is the physical and chemical decomposition of organic matter with heat, in the absence of oxygen. The result is a complex mixture of a low BTU gas, a low grade fuel oil, and a solid carbon residue that contains ash and inert materials. The product composition and yield can be regulated by varying the conditions of pyrolysis: waste composition, residence time, temperature, pressure, prior treatment of the waste (size reduction, drying, removal of inorganics), catalysts, and oxidizing and reducing reactants.

A number of pyrolysis systems are being developed. The Monsanto LANDGUARD process produces a very low BTU nontransportable gas. The Garrett Research and Development Process produces a low sulfur fuel oil. The Union Carbide PUROX process produces a transportable fuel gas. Of these processes, the PUROX process, using a controlled amount of oxygen rather than eliminating it, is considered to be the most advanced in its stage of development.[2] This process produces a 370 BTU per SCF (standard cubic foot) synthetic fuel gas and an inert glassy residue. This syngas is clean burning and transportable. The gas can be used for energy or as a chemical feedstock to produce ammonia, methanol, or methane. In the Monsanto Process, the low BTU gas must be immediately combusted to produce steam to conserve its energy, but without particulate removal by wet scrubbing which would further reduce its heat energy, there may be emissions problems.

The value of pyrolysis lies in its basic flexibility. The formation of the fuel and its combustion to provide energy can be separated in time and space. Changes can be made to vary the products especially since the chemical products may be more valuable than the fuel itself.

Energy can also be recovered from solid waste by incineration of raw refuse or refuse-derived fuel (RDF), the lightweight combustible fraction of solid waste. The heat value of raw refuse is 3000 to 8000 BTU's per pound and that of RDF is 6700 to 8500 BTU's per pound.[4] Furthermore, RDF can be pelletized (or densified) to an even more homogeneous, more easily storable and transportable fuel. The difference between incineration and pyrolysis is that pyrolysis is endothermic (yet produces more energy than is consumed) and produces primarily carbon monoxide and hydrogen rather than carbon dioxide and water. Steam production from incineration may fluctuate severely if the waste is not reasonably homogeneous in BTU content or moisture content, and the gases are highly corrosive. Therefore, the burning of raw refuse or RDF may not be suitable for electricity generation except as an auxiliary fuel to deal with fluctuations in supply and demand of fuel and energy.

In incineration, a waste heat boiler extracts heat from the hot gases producing steam. These exhaust gases are further combusted and cleaned before release to the atmosphere, but it may be difficult to meet air quality standards. There are also the problems of corrosion of the boilers, the burning of very wet refuse, and the reliable delivery of steam. RDF can also be combusted with pulverized coal which would neutralize the corrosive qualities of the solid waste, but environmental considerations make the use of coal as an energy source highly unlikely in the Bay Area. An alternative which does not include the conventional waste heat boiler is the CPU-400, a process in which the hot gases are utilized directly to drive a gas turbine to generate electricity.

Sewage sludge can also be used as a fuel, but because of its high moisture content, little or no heat is produced. It can be utilized with solid waste, but the resultant gases would be higher in nitrogen and sulfur so may require a different fuel gas cleanup scheme. Its air pollution effects are unknown.

Another method of energy recovery is tapping the gases emitted from landfills, which can be hazardous if not tapped. They consist mainly of carbon dioxide and methane, have a heat value of around 500 to 600 BTU's per SCF (about half that of natural gas), and would be wasted if not tapped. After cleaning, the gas is essentially pure methane with a heat value of 1000 BTU's per SCF. This year, PG&E is planning to drill the Mountain View Sanitary Landfill with a possible recovery of one million cubic feet of uncleaned gas per day (cleaning would result in a 40 per cent reduction of gas volume). Tapping this gas would alleviate the pollution by methane, but because there are a limited number of landfill sites, and only a few are ideal for this mode of recovery, only a minor amount of gas would result.

Environmental Impact

The burning of solid waste, though low in sulfur, produces corrosive and noxious gases. The heterogeneous nature of solid waste makes control of emissions difficult. The disposal on land of the residue resulting from these processes, which may be mainly tin cans and metallic objects, could cause a leachate problem because of the small amount of soluble material left. Shredders for size reduction of the solid waste may be noisy but can be housed in soundproof buildings in an industrially zoned area.

In incineration, with complete burning, complex compound emissions are low. At normal operating temperatures, the production of carbon monoxide and nitrogen oxides is minimal. Particulates, the major pollutant, as well as other pollutants could be dealt with by scrubbers and electrostatic precipitators, but even sophisticated equipment may not be able to meet pollution standards. Heavy metals in the water used to quench the incinerator residue would constitute a public health hazard unless there is on site treatment of the water. Dust generation from handling, processing, and burning solid waste requires effective collection systems for suppression and control of dust, which could cause explosions and fires. In production of RDF, water pollution is minimal (if produced by a dry process). The pollution effects of burning RDF are not known. Existing boilers would need new air pollution control equipment to deal with the new fuel. Electricity production via the CPU-400 should be minimally polluting because the process involves combustion at high temperature and pressure, coupled with three stages of particulate matter removal.

In pyrolysis, the volume of gas produced is much smaller than in incineration, and emissions would be much easier to control with careful cleaning. There are few unburned hydrocarbons, and nitrogen oxides should be minimal and can be dealt with by scrubbers and electrostatic precipitators. In the Monsanto process, producing steam directly by pyrolysis, all the used water can be recycled, with a moderate amount of excess water going to the sewer, which should not change the influent characteristics at the water treatment plant.[14] There may be emissions problems because it is not feasible to clean the gases with wet scrubbing before steam production, which would reduce the heat value of the gases. The oil-water phase, which is the result of water in the system combining with the oil produced, may contain complex organics which require biotreatment or recovery.

In pyrolytic fuel production by the Purox process, acidic gases can be dealt with by an acid absorber and flyash could be recycled back to the furnace where it would leave with the residue. With 27,000 gallons of waste water generated per 1000 tons of waste,[12] our present water shortage makes the use of such great quantities of water feasible. The gas itself has similar combustion characteristics to natural gas which is considered the cleanest fuel so burning the gas should present no problems.

Cost

The economic feasibility of these processes is basically related to their ability to recover energy, but for many systems feasibility is also dependent on revenues from recovered products. The generation of steam or electricity for sale has, as with other products, its own marketing problems of supply and demand, quantity, transportation, and competition. Standby fuel may also be necessary to produce the contracted quantities of energy during periods of low refuse heat value. Steam is limited to short transportation distances and must be delivered as produced or lost. Thus, steam production for sale is attractive only under restricted conditions. The production of electricity is also inflexible because, like steam, it is not storable and must be sold as produced. Electricity generation also requires higher capital and operation costs. Pyrolysis fuels are storable to some extent and have a strong market. RDF production would require the lowest capital and probably would have a market with the public utilities and industry, but requires modified operation of the facilities.

Disposal of solid waste in landfills currently costs about $3 per ton.[2] The overall economics of the alternatives to land disposal can range from profitable to costly depending on market conditions. Present data can become quickly obsolete and building and disposal costs are very site specific. In addition, plant design may need to be modified to meet local user specifications for energy or products.

RDF production and combustion to steam would have a net cost from a minimum of $4 per ton[2] to a maximum of $8 per ton at a minimum plant size of 300 TPD (tons per day).[3] Since the market for RDF is limited, perhaps only a small subcounty plant could be used. Production of densified RDF would increase costs by about $2 per ton,[2] but its market is greater, and with the economy of increasing scale, a one million TYP (tons per year) RDF plant could have a net cost of $3.50 per ton.[2] Conversion of boilers to accommodate solid fuel requires considerable air pollution control costs. Since steam quality is not high, it is probably best as an auxiliary fuel to deal with fluctuations.

Pyrolysis is very capital intensive with poor economics of scate. High net costs of $14 per ton at 1000 TPD may be reduced to $7 per ton at 11,000 TPD.[2] The use of the gas may require new burners since it is a lower BTU gas than natural gas. Pyrolysis would be most economical on a regional basis with a single county

200,000 TPY plant having a net cost of $18.75 per ton and a multi-county plant of 4 million TPY having a net cost of $7.25 per ton.[2]

The Central Contra Costa Sanitary District is planning to pyrolyze sewage sludge with RDF. It has been estimated that the process could meet all the natural gas requirements of their water reclamation plant by 1980. They estimate the capital required for the project to be $25 million, but federal and state funding would reduce costs to $1 million per year. The plant would save $5.6 million of power and fuel each year. Their off-gas scrubbers are still to be designed to meet the Bay Area Air Pollution Control District's emission standards.[7]

Only a small fraction of syngas would be usable in existing natural gas lines because dilution with natural gas is necessary to reduce its corrosive properties and toxicity (high in carbon monoxide), and to make it more uniform in composition and heat value. Because of its high carbon monoxide content, the gas is not suitable for home use. It has approximately one-third the heat value of natural gas and could be used as a substitute or supplementary fuel. It is most feasible for interruptible industrial customers clustered in an area so that a very costly, extensive distribution network is not necessary.

Because of the variety of products possible, each with its own processing costs, revenue can vary markedly. Methanol, which can be regarded as storable fuel, has a small market in the Bay Area, but potential revenues are high--$35 per ton of waste. Hydrogen has a small market also, but has the highest potential revenue--$82 per ton of waste.[2] Hydrogen is the cleanest fuel known, but production costs are high. It is thus necessary to find an optimum product mix geared to local needs.

In comparison with natural gas, RDF and syngas, as fuels to produce power (at minimum cost and 100% efficiency), would be substantially more costly. RDF would be at least twice as expensive, and syngas at least three times as expensive.[4]

Conclusion

The disposal of solid waste in landfill sites constitutes a loss of valuable resources and is energy consuming. Energy, resource and product recovery from solid waste would not only conserve resources but also reduce the amount of landfill required. Solid waste should be considered as an attractive energy source.

Dr. Diaz has estimated that conversion of residential/commercial wastes to syngas or RDF could provide 8 to 10 per cent of the interruptible industrial gas requirements in the Bay Area in 1978,[4] or about 3% of the total gas requirement in that year.[1] This is a significant amount because it is expected that only 61% of interruptible industrial natural gas requirements will be met by PG&E, as compared to the 96% supplied in 1974. In 1983, the natural gas supplied by PG&E could be as low as 17%.[4] The interruptible market will find it necessary to turn to alternative fuels. Because the feasibility of these processes is determined by revenues, more marketing information, which is essential to planning and design, is needed.

Direct combustion is the most economical alternative, yet the least is known about its air pollution effects. Steam could have a large potential market, but we lack sufficient data. Since there are no coal-fired facilities in California, there is a limited market for RDF and also, there is a lack of data on retrofitting existing boilers to deal with the air pollution.

Pyrolysis is the most environmentally acceptable and the most versatile method because it produces a gas which can be a direct substitute for natural gas, but it cannot be used domestically because it is highly toxic and explosive, and when cleaned, is odorless. However, there is a strong commercial market--PG&E and its interruptible industrial natural gas customers.[2]

Pyrolysis gas is the most convenient fuel form, but it is capital intensive to produce (a minimum of 3 to 5 times higher than for RDF). Solid fuel is less attractive as a fuel because major process changes are necessary, but it is less capital intensive to produce.[4] Also, emission standards are more stringent for gaseous fuels than for solid fuels so pyrolysis gas is more environmentally acceptable.[2] Large scale regional pyrolysis and small scale combustion of RDF where local markets exist for steam could very well be economically feasible. In addition, because of the nature of the fuel produced, these new fuels would benefit only the industrial sector unless utilized by utilities.

Flexibility is essential to meet future changes in waste composition and quantities, in marketing, and in pollution standards. Even if we could meet pollution standards now, we have no guarantee that we can meet them as they become more stringent. In the future, product recovery revenue and waste quantity can hardly be assured.

Although energy and resource recovery is much better than simple disposal in landfill, the use of solid waste as a fuel provides no incentive to conserve. This defeats our purpose of conserving energy and resources. In addition, resource recovery is the only opportunity immediately implementable; the others require more time. It would be more practical to reuse paper, the major constituent of municipal refuse, several times before using it as an energy source where the fiber is lost forever. Therefore, it is my opinion that recycling and recovery of resources is more acceptable at the present, both economically and environmentally, than energy recovery

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