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Economic Appraisal of the Rapid Catalytic Cracking Development Scheme for Municipal Solid Waste

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Abstract
There are a wide range of modern waste disposal systems and the costs of operating them greatly vary. The type of waste disposal system to be used is selected based on the nature of the operation, process and needs of the local community. In Iran, mixed municipal waste with significant contamination and humidity is prevalent. As a result, the most commonly used methods implemented in European and American countries are not applicable in Iran and in many cases, investments on these technologies have failed. Among the methods that have attracted the attention of authorities and urban managers are the mixed waste disposal approaches associated with positive economic returns such as Rapid Catalytic Cracking systems (RCC). In this study, the economic aspects of implementing an engineering investment model on a typical RCC unit is studied in order to evaluate the economic development of the project regarding the local and regional conditions and challenges. The data collected in 2017 were used in this study and results were obtained using COMFAR. The internal rate of return (IRR) of an RCC system with a capacity of 180 tons per urban waste for a lifespan of ten years is 80.23%, which indicates there is a very attractive economic justification for the scheme compared to the interest rate (20%).
Keywords: Catalytic Cracking, Pyrolysis, Municipal Waste, Economic Evaluation, COMFAR.

Introduction

Statistics show the daily production of 3.5 million tons of municipal waste in the world, with Iran's share of 40 thousand tons per day (https://eform.doe.ir). Two most common methods of waste disposal in Iran are burial and garbage disposal. These methods impose direct and indirect costs and disadvantages on individuals. According to the World Bank estimates, a reduction of 25 to $ 100 per tons of trash can be achieved from country information centers (World Bank, 1999). Due to the deductions of waste disposal methods' funding, including transport, burial, burning, manpower, and equipment used by ordinary people under the title of the tax or service, the

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elimination of these costs is considered as an economic process. Hence, the economic review of the waste disposal development plans for the optimization of comprehensive waste management in developing countries is very important, and the right choice can make a very positive change in the future of the community. An economic assessment provides the opportunity to determine the attractiveness of an industrial project (Rashidi et al. 2013). Given the time value of money, the following criteria can be used to compare different economic projects. Therefore, with the advent of new technologies worldwide, the economic issues and their profitability which can be fluctuated due to the regional and native conditions are among the main questions of the technology developers. Some of the literature is provided as follows.

Nelson et al. (1994) conducted an economic assessment of a plant producing 100,000 tons of biodiesel per year. Noordam and Withers (1996) conducted an economic study on a biodiesel production plant with a capacity of approximately 7,800 tons per year.

Haley and Ugursal (1997) made the feasibility of using a geothermal heat pump in cold weather. Bender (1999) compared the economy of seven biodiesel power plants using different oily seeds (such as soybeans, rapeseed, sunflower seeds and rapeseed) or animal oil as raw materials (Bender, 1999).

Petit and Meyer (1998) compared the economic potential of geothermal heat pumps with air-conditioning systems in South Africa. In order to conduct this study, calculation of the initial investment costs and operating costs was done, and ultimately gained the return on investment, net present value, and the rate of internal return. Using the ALCC method, Esen et al. (2006) compared the economic analysis to estimate the GSHP system for heating in a region in eastern Turkey with conventional heating methods (electrical resistance, crude oil, gasoline gas, coal, oil and natural gas). Mahmoudi & Mahdavi (2011) conducted a financial and economic assessment on tourism service projects in the city of Dalahu, Kermanshah province, using COMFAR software. For this purpose, first, the initial information including the number of passengers was predicted and, along with other data, carried out various analyses into the COMFAR software outputs.

Aghaei et al. (2013) reviewed the construction feasibility of a hypermarket in Mashhad. To this end, by collecting pre-paid costs and entering COMFAR software, they discussed and concluded with regarding the IRR achieved via the software. Rashidi et al. (2013) conducted an economic appraisal of the geothermal heat pump in Taleghan, and considered the construction time to be 6 months with 25 year of the useful life of the project. Collecting the costs, data were entered into the Kamfar program and extracted the NPV, IRR, LEC and PP from the program.

One of the innovative technologies in the field of waste management is the new disposal methods associated with a systemic justification and profitability approach. With the advancement of technology- dumping or disposal of waste- there are not any other economical and cost-effective options, which would eliminate the potential for significant surplus value creation. One of the new methods of waste management, based on economic justification and the focus on solving countries' and communities' issues face mixed and contaminated waste, are pyrolysis methods, particularly the rapid catalytic cracking method. Generally, it is known as melting by adjacent heat without the presence of oxygen cracking or pyrolysis.

Vahidi et al. (2014, 2017b), studied two types of municipal and industrial wastes disposal systems. A variety of waste disposal scenarios have been subjected to environmental assessment, and lack of economic assessments along with environmental assessments were the significant points of these studies. This is one of the main weaknesses in the evaluation-based literature in Iran, which does not pay enough attention to the economy of environmental projects. Vahidi et al. (2017a) describe the heart-rending economy as the sustainability guarantor of a development plan.

As a result, a thorough study on the economic assessments of new ideas in the environmental field leads to the more accurate appropriate decision makings along with more continuity guarantees for the society.

In this study, an economic assessment is conducted on an innovative and new process, based on the combination of catalytic pyrolysis and rapid cracking techniques. The method designed specifically for the municipal mixed waste of Iran. This process has not been yet used in Iran and to the best of our knowledge in the Middle East, and is applied only as pilot study.

Figure 1. RCC pilot and its product

The production speed in this process is more than twice faster than other catalytic cracking processes. It should be mentioned that the major technologies imported from European countries into Iran are only capable of cracking petroleum products and cannot be used for municipal wastes. Main goals and benefits of this technology are as follows: waste to energy conversion, co-financing of financial and other facilities of the country in the field of waste management, environmental protection, reduction of environmental pollutants, wealth generation, cheap and affordable fuel production, passive defense, reduction of municipal expenditures, improvement of public health and public health.

1. Implementation of RCC project in different cities of the country addresses the cost of disposal and management of municipal waste (about 30% of the total cost of the municipal services), and can save a great amount of money in this institution.

2. One of the important factors of environmental pollution is the traditional waste disposal systems, which is now considered as one of the most critical problems in the country, especially in northern provinces. Water, soil and air pollution are the most important contaminations that result from inappropriate waste disposal and cause many human and environmental threatens, including cancer and various diseases in the community. Unfortunately, due to the mixed waste composition in Iran, European and western systems do not meet the needs of the country. As a result, a native system adapted to mixed waste can solve this issue. The RCC technology-driven system is one of the least polluting waste disposal systems.

3. Cheap energy is always known as one of the most important fields for the development of various industries in an area. Using RCC technology, the energy from waste is much cheaper and more justifiable compared to other clean energy sources, which allows the infrastructure development of the industries to provide in the region, especially the energy-related industries.

Therefore, in this paper, the use of economic evaluation methods of industrial designs and engineering models are studied to evaluate the profitability and the justification of this technology in a medium dimension. The evaluation was conducted considering the per capita amount of municipal wastes production and the population of middle-sized cities of the country. The results of this study may have a significant impact on the attitude of officials, managers and investors towards new types of waste management technologies in the country and worldwide.

Materials and Methods

In order to study the economic feasibility of a system, various methods can be used for the evaluation. Some are as follows:

Current Net Value Method (NPV), Internal Rate of Return (IRR), Annual Cost Method (AC), etc.

Net present value

Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows, based on the expected discount rate. NPV can be calculated using the equation below:

$$NPV = -P + \sum_{m=1}^{n} \frac{A}{(1+i)^m} \quad (1)$$

Where P, A, i and n are the initial capital, net cash inflow during the period t, interest, and life expectancy of the project, respectively.

A positive NPV value indicates that the project's profits are higher than the discount rate, and as a result, the project is acceptable while the negative NPV indicates that the project has been rejected.

Internal rate of return

Solving the following nonlinear equation, the actual benefit of a project that can be achieved as IRR:

$$-P + A\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right) = 0 \quad (2)$$

While the project's IRR is more than the expected interest rate, the project can be opted for investment.

COMFAR Economic Evaluation Scheme

The United Nations has been working with governments, business communities, and industrial organizations for over 30 years to solve economic problems. One of the tools developed to serve this purpose by UNIDO is the COMFAR program, which is a computer model for feasibility analysis and reporting. In 1983, the first version of COMFAR was produced. Since then, the United Nations has been continuously working to improve and develop this tool. During the development of this program, the experience of 30 economic evaluation committees from different countries has been used. The production cost of the program was 1.5 million $, which more than 0.5 million copies in 15 different languages have been released worldwide. In addition, experts in more than 140 countries use this program to evaluate production and service plans and projects and choose the best options for investment (www.unido.org/comfar). The third edition was released in 1995 under the title of COMFAR III Expert. From then on, it was upgraded to meet technological developments and users' requests annually. In 2003, COMFAR was introduced in Iran, which has been used as the main tool for evaluating industrial designs and providing justifiable results for national development plans.

Discussion and results

Components of economic calculations

The general information about the project discussed in this paper is shown in Table 1.

Table 1. Costs of Construction Phase

Project name	Production of fuel from urban waste
Start date	2018
Construction time	One year
Raw material	180 tons per day of waste
Design Capacity	25,600,000 liters per year
Discount rate	20%
Estimated sales for the first year	85% of capacity
Estimated sales for the first year onwards	100% of capacity

Costs are divided into fixed (direct, generating), indirect (non-productive), working capital and production costs separately, as described as follows.

Direct fixed capital costs

Direct initial costs include the cost for purchasing different types of equipment, required buildings and spaces at the factory, landscaping, and equipment costs, as described below.

Manufacturing machinery cost

List of the main sources of diesel waste extracted from municipal waste using this method, with a capacity of 250 tons per day, is given in Table 2. Estimated prices are calculated based on domestic production. It should be noted that costs for instrumentation and control, plumbing and electrical equipment are 500,000, 750,000, and 300,000 $, respectively.

The cost of required buildings and spaces at the factory

Estimations for required buildings including process and public buildings, maintenance workshops and safety departments and construction facilities are given in Tables 3 and 4. It should be noted that land acquisition costs is considered 0.

Landscaping

Estimated landscaping including development of site, cleaning, smoothing, roads, fences, etc. are presented in Table 5.

Table 2. List of main equipment

Total Price ($)	Number	Unit Price ($)	Specifications	Machine
900,000	6	150,000	30 tons per turn - 316 stainless steel	Cracking reactor
275,000	1	275,000	100 tons in turn - Steel 316	Distillation
10,000	1	10,000	100 tons in turn	3 fuzzy separator
15,000	1	15,000	Vacuum pump 15 kW	Vacuum equipment
10,000	1	10,000	100 tons in turn	Hot oil boiler
62,500	1	62,500	20 in turn	Hydrogen production reactor
50,000	1	50,000	1 in turn	Electrochemical unit
250,000	1	250,000	50 tons per turn	Reforming tower

Table 3. Required Buildings' Area

Part	Area (m²)
Production building	5000
Production services	2000
Maintenance buildings, facilities	1500
Office buildings	400
Area of land needed by the factory	26700

Table 4. Construction and construction

Part	Total Cost ($)	Unit cost ($ per square meter)	Area (m²)
Production building	350,000	125	2800
Production services	250,000	125	2000
Building repairs, facilities	192,500	175	1100
Office buildings	90,000	225	400

Table 5. Landscaping

Total cost ($)	Unit cost ($ per square meter)	Area (m²)	Part
50,062.5	1.875	26700	Leveling
16,375	12.5	1310	Fencing
100,125	37.5	2670	Streetwalk and green space

Production auxiliary equipment

The amount of equipment and facilities estimations for production include utilities (steam, water, electricity, compressed air, fuel, waste treatment), water and wastewater treatment, cooling tower, air unit, water and fuel storage tank, fire extinguishing, transportation, distribution, packaging etc. Table 6 shows the estimations.

Table 6. Total cost of equipment on the side of production

Part	Number	Total price ($)	Unit Price ($)
Single power split	1	187500	187500
Product Storage Tanks	4	100000	25000
Diesel Generator (Generation)	1	78125	78125
Diesel Generator	1	25000	25000
Water production facilities	1	85000	85000
Wastewater treatment plants	1	35000	35000
Water split	1	10000	10000
Water Tanks	1	575	575
Fire extinguishing facilities	1	15000	15000
cooling tower	4	30000	7500
Steam equipment	2	25000	12500
Air cleaning facilities	1	22500	22500
Compressed air facilities	3	15000	5000
Heating and cooling installations	1	11250	11250
Loading and unloading terminal	1	125000	125000
Transmission equipment and large workshop equipment	1	150000	150000

Indirect fixed capital costs

Indirect fixed capital costs include engineering and monitoring costs, legal costs, indirect construction costs and unexpected costs, which are explained as follows.

Engineering and monitoring costs

Engineering and monitoring costs include design costs, drawings, technical and economic reports, missions and travels, consultations, etc., which is estimated 246,250 $.

Legal Fees

Legal fees includes licenses, approvals, contract negotiations, etc., which is equivalent to 100,000 $.

Indirect construction costs

Indirect construction costs include temporary structures, quality control, staff (before operation) etc. and is equivalent to 538,750 $.

Unpredictable costs

Unpredictable costs include natural disasters, strikes, price changes, estimated errors, etc., which is equivalent to 375,000 $.

Working capital

Working capital is considered to be the credit required for assets and current materials and supplies in the calculations. In order to determine working capital, the amount of inventory, the amount of cash needed for payment of expenses and the amount employer debt, suppliers, etc. must be calculated. The determination method for each of the circulating capital sectors amount is presented in Tables 7 and 8.

Table 7. Storage inventory

Cost Description	Cost ($)	Day
Municipal waste	0	30
Industrial hydrocarbon waste	0	30
Aluminum scrap	26250	30
Catalyst and additives	255000	100
Energy	31800.64	30
Produced diesel	173713.2	7
Production naphtha	55371.09	7
Aluminum ingots produced	17500	7

Table 8. Amount of cash required, except for the cost of employees

Cost Description	Duration/ day	Cost (Rials)
Operating costs of production (costs of employees and forced labor)	30	43227

Production costs

Production costs include raw materials, production staff, manufacturing requirements, maintenance, fixed costs, overhead expenses, and public expenditure. Each of mentioned were examined separately.

Raw materials

Costs for raw materials include urban municipal waste, aluminum scrap and chemicals, which are listed in Table 9. It should be noted that there is no cost for city rentals.

Table 9. Substances

Part	Unit	Unit Price ($)	Annual cost ($)	Daily amount
Municipal waste	Ton	0	0	130
Industrial hydrocarbon waste	Ton	0	0	50
Aluminum scrap	Ton	875	288750	1
chemical materials	Kilograms	6	841500	425

Production staff

The required staff for the manufacturing sector is shown in Table 10. It should be mentioned that the surplus coefficient of 1.3 is applied to salaries.

Table 10. Manufacturing staff costs

Number of employees	Number	Monthly salary ($)	Turn	Annual salary ($)
Factory Manager	1	1500	1	18000
Manager	1	1250	1	15000
Engineer	1	1000	3	36000
Technician	1	675	3	24300
Worker	10	375	3	135000
Driver	2	450	3	32400
Guardian	3	450	3	48600

Production side requirements

According to Table 11, the supply side requirements include fuel, electricity, steam, sewage treatment, process water, cooling water, etc.

Table 11. Production side requirements

Part	unit	Unit Price ($)	Annual consumption	Cost ($)
Electricity	Kilowatt hours	0.015	7,128,000	107158.1
Fuel (electric)	Liters	0.18	712,800	128304
Fuel (steam)	Liters	0.18	247,500	44550
Process water	Cubic meter	0.5	74,250	37125
Non-process water	Cubic meter	0.000132	247,500	32670

Repair and maintenance

Table 12 presented the maintenance costs in the three parts of the building and landscaping, main and production equipment.

Table 12. Maintenance

Description	Share of repairs and maintenance (%)	Total investment ($)	Cost ($)
Buildings and enclosures	2	1049063	20981.25
Main production equipment	4	1572500	62900
Production equipment	5	914950	45747.5

Fixed production costs

Fixed production costs include depreciation, property tax, financial resources, profit from loans, leases and insurance, which is controversial in how they are calculated.

Table 13. Annual depreciation costs of fixed investment

Description	Depreciation (%)	Detailed description of investment ($)	Cost ($)
Buildings and enclosures	3	1049063	31471.88
Main production equipment	10	1572500	157250
Production equipment	7	914950	64046.5

Overhead costs

General overhead costs of the factory, rewards, health services, safety, rehabilitation, laboratories and warehousing facilities are equal to 467785.25 $.

Public expenses

According to tables 14 and 15, public expenses include administrative expenses. It is worth noting that the surplus coefficient of 1.3 is applied to salaries.

Table 14. Public expenditure

Description	Cost ($)
Distribution and sales	148916.8
Research and development	29783.35

Table 15. Administrative staff

Number of employees	Monthly salary ($)	Turn	Number	Annual salary ($)
CEO	1250	1	1	15000
the manager	1000	1	3	36000
Administrative Officer	625	1	12	90000
Driver	450	1	2	10800
Watercolor	375	1	2	9000
Secretary	450	1	1	5400

Results of reports generated by COMFAR

In this study, the IRR and NPV economic criteria are calculated using the COMFAR software. Since the system life expectancy is an effective factor in economic assessments, the results of IRR for 10, 15 and 20 years are presented in Table 16. In this scheme, the discount rate is 20%.

Table 16. Results for different expected lifetimes

Expected life	IRR
10	80.23
15	80.03

The results presented in Table 16 show that increasing longevity does not make the project more interesting from the economic aspects. It is crystal clear that the system lifetime is affected by the maintenance plans and operating conditions. Therefore, improvement of these processes leads to the increase in the economic benefits of the system. Despite this, the project with a 10 year lifespan is the most economical project and other results are considered for this project. Since, in this paper only direct costs are taken into account, it should not be considered a disadvantage for the achieved results. It should be noted that in these environmental-related projects, whether for the public or for government experts, indirect costs are also very important and critical in some cases. As an example, with the spread of diseases, the treatment costs, etc., increase for individuals, and with the spread of water, air and soil pollution, a lot of costs involved in spread prevention, control and reduction of caused pollutants to the state organs.

Net present value (NPV) and IRR sensitivity and changes

The net present value, rendering COMFAR is shown in Figure 2. Also, the pattern shows the sensitivity and variation of IRR relative to the three factors of sales revenue, fixed capital cost and operating costs.

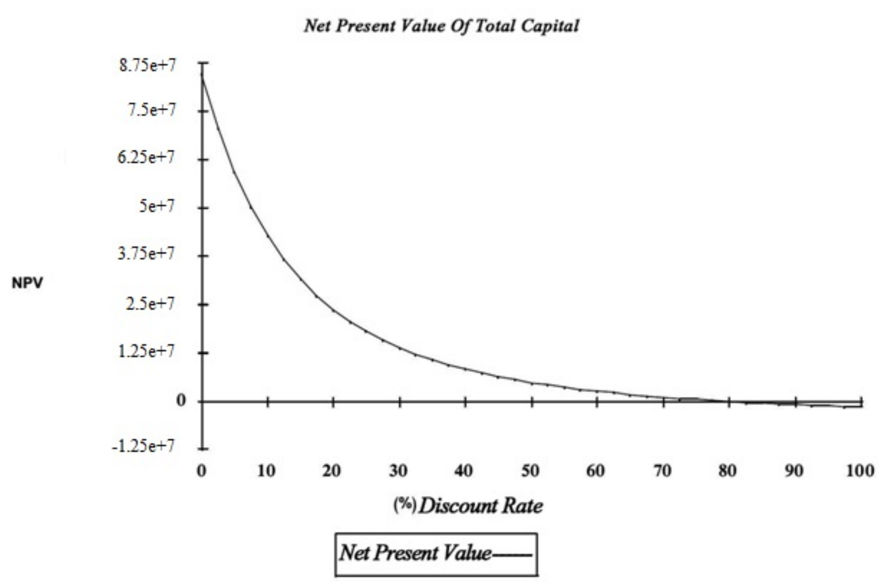

Figure 2. Net present value of total capital

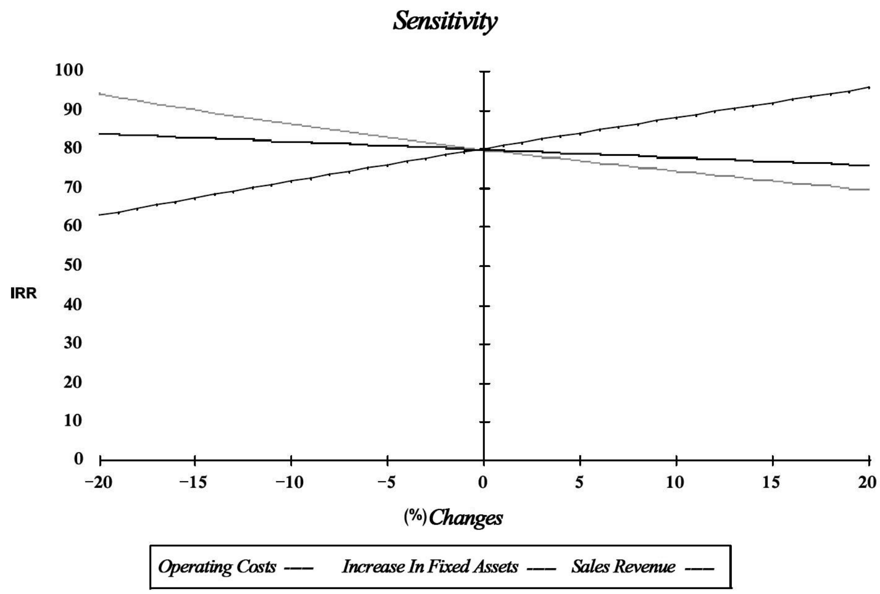

Figure 3. Sensitivity and IRR changes

Conclusion

The purpose of this study was to investigate the economic feasibility of developing rapid catalytic cracking systems for urban waste and investigate the amount of revenue generated via the production of liquid fuel by the waste disposal system. Urban waste disposal is one of the costliest tasks of municipalities and so far the government has not succeeded in making economically feasible plans for waste disposal. Development of integrated municipal waste management systems in the country can be a viable solution in this regard. In this study, using the data collected in 2017, modeling was performed in COMFAR and the results were achieved. Results showed that for an RCC unit with a lifespan of 10 years, the internal rate of return (IRR) was 80.23% indicating good economic justification for the plan compared to bank interest rates (15-20 %). Therefore, according to the results of this study, it can be concluded that the rapid development of catalytic cracking units as fast-growing firms with good profitability can have a significant effect on local incomes in all of the medium and large cities of the country. Development of RCC units at national level can lead to good financial gains while having other benefits including positive effects on the environment, economic resilience, reduced dependence on petroleum products, and the possibility of increasing oil exports, passive defense by generating fuel in different parts of the country.

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