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a. NAME *(Last, First, Middle Initial)* Marqusee, Jeff (or Kelly, Amy 696-2124)	b. TELEPHONE NO. *(Include Area Code)* (703) 696-2120

5. PRIOR COORDINATION

a. NAME *(Last, First, Middle Initial)*	b. OFFICE/AGENCY	c. TELEPHONE NO. *(Include Area Code)*
Boyd, Robert	ODDR&E (Biosystems)	(703) 588-7401

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Closed Loop Energetics with VOC Emission Reduction (CLEVER)

June 2003

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
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LIST OF ACRONYMS

A/F	Acetal/Formal
ARL	Army Research Laboratory
ATEC	Acetyl Triethyl Citrate
BIC	Ballistic Impact Chamber
CAA	Clean Air Act
CAB	Cellulose Acetate Butyrate
CLEVER	Closed Loop Energetics with VOC Emission Reduction
CWA	Clean Water Act
DD	Dahlgren Division
DDT	Deflagration-to-Detonation Transition
DoD	Department of Defense
DOE	Design of Experiments
DSC	Differential Scanning Calorimetry
EC	Ethyl Centralite
ECAM	Environmental Cost Analysis Methodology
ERGM	Extended Range Guided Munition
ESH	Environmental, Safety and Health
ESTCP	Environmental Security Technology Certification Program
FY	Fiscal Year
IHDIV	Indian Head Division
IHTR	Indian Head Technical Report
ILLUM	Illuminating Round
IPT	Integrated Product Team
IRR	Internal Rate of Return
LOVA	Low Vulnerability Ammunition
LRIP	Low Rate Initial Production
MEK	Methylethylketone
MJ	Megajoule
NC	Nitrocellulose
NPV	Net Present Value
NSFS	Naval Surface Fire Support
NSWC	Naval Surface Warfare Center
OMB	Office of Management and Budget

LIST OF ACRONYMS (continued)

PBX	Plastic Bonded Explosive
RAAP	Radford Army Ammunition Plant
RCRA	Resource Conservation and Recovery Act
RDT&E	Research, Development, Test & Evaluation
RDX	Hexogen
SEM	Scanning Electron Microscopy
SOP	Standard Operating Procedure
TCIS	Thermal Catalytic Incineration System
TOC	Total Ownership Cost
TSE	Twin-Screw Extruder
VCCT	Variable Confinement Cook-off Test
VOC	Volatile Organic Compound
WA-XRD	Wide Angle X-Ray Diffraction

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

Every year the Department of Defense (DoD) produces thousands of pounds of solvent mixed energetic materials in the production of gun propelling charges. The solvents tend to be volatile organic compounds (VOC). The conventional propellant production method (Batch process) does not recover or recycle the solvent VOC emissions. The untreated VOCs are allowed to be released into the atmosphere.

The Closed Loop Energetics with VOC Emission Reduction (CLEVER) process is a radical change from the conventional manufacturing method which typically loses one pound of solvent directly to the atmosphere for every three pounds of propellant made. The CLEVER process is defined as a precipitation process followed by processing in a twin-screw extruder (TSE). The precipitation process, developed, and patented by Nexplo-Bofors in Sweden (see reference 1) replaces conventional ingredient preparation and mixing. It is a closed loop process that fully dissolves all propellant ingredients into solvent and then processes the solution through a steam precipitator. The precipitator is used to evaporate the solvent thus precipitating a propellant powder. The evaporated solvent is recovered and recycled. The dried propellant powder is resolvated in a TSE for final extrusion and cutting. Data on solvent usage, emissions, and scrap generation were collected during both the precipitation process and twin-screw process to allow comparison with data developed from conventional production records.

1.2 DEMONSTRATION OBJECTIVES

The objective was to demonstrate the ability of the CLEVER process to cost effectively produce acceptable propellant while significantly reducing the emission of VOCs and the generation of hazardous solid waste. The vehicle chosen for the demonstration was the production of two small lots of EX-99 propellant grains for testing in the new Extended Range Guided Munition (ERGM) round for the Navy’s five-inch gun.

1.3 REGULATORY DRIVERS

Code of Maryland Regulation 26.11.19.25 states “the owner or operator of existing explosives and propellant manufacturing equipment subject to this regulation shall install a VOC control device having a VOC destruction or removal efficiency of 85% or more overall on all active nitramine propellant manufacturing equipment that has a capacity of 150 gallons or more.” The nitramine manufacturing facility is centered around a 150-gallon batch mixer. Currently, over $1,400,000 is being spent to install a Thermal Catalytic Incineration System (TCIS) at this facility. This system was installed because it was the only viable pollution control solution available at the time. Operating at its projected 99% efficiency, this system will reduce the VOC emissions from the current 27.0 lb/hr to 0.27 lb/hr during normal operations. This solution provides VOC emission reduction at the mixer only.

The Clean Air Act (CAA), Clean Water Act (CWA), and the Resource Conservation and Recovery Act (RCRA) are other underlying regulatory issues that emphasize the nationwide reduction or elimination of hazardous materials or waste. CLEVER will significantly reduce waste amounts by replacing both the grinding and mixing operations with the precipitation process. The precipitation process lowers waste significantly because of the recycling done on most of the resulting wastes. Waste is also reduced in the TSE process by replacing the mixing, blocking, straining, and extruding processes with one continuous process.

1.4 DEMONSTRATION RESULTS

The CLEVER process demonstrations conducted between the Fall of 1997 and Spring of 2000 were highly successful. The CLEVER process demonstrated the ability to reduce VOC emissions by 47% and hazardous solid waste (scrap propellant) by 50% while reducing propellant cost (based only on labor and materials) by 41% costs. Using the net present value method, which includes facilities amortization costs, a net savings of 18% is realized when compared to the conventional batch process. The propellant quality was equal to or better than comparable batch produced propellant. Both demonstration lots were successfully gun fired and performance as measured by muzzle energy, chamber pressure, and velocity variation were outstanding, as good or better than any propellant that has been tested to date. On the critical parameter of muzzle energy, the CLEVER propellant exceeded the 18 MJ minimum requirement without exceeding the maximum breach pressure (65,000 psi).

1.5 STAKEHOLDER/END-USER ISSUES

The CLEVER project has designed and engineered pollution prevention into the process while utilizing a comprehensive, multi-pronged approach to ensure both regulatory compliance and regulator and stakeholder acceptance of the CLEVER process. The CLEVER strategy for implementation includes: (1) openly engaging Environmental Division personnel throughout the construction and operation of equipment and facilities; (2) identifying major regulatory drivers applicable to energetic materials production, assessing the environmental, safety, and health (ESH) issues and impacts associated with energetic material chemical constituents, and quantifying waste streams; and (3) ensuring stakeholder participation throughout the process.

This approach has served to enhance the standing of Indian Head Division among federal, state, and local regulators and the surrounding community by demonstrating the installation's commitment to environmental protection and the minimization of safety and health hazards to workers and the surrounding community.

The evaluation of the CLEVER process is very timely. Typically, it is difficult to insert new processing technology into ongoing programs. However, in this case, the Navy is currently developing two new propelling charges for the five-inch gun. The Navy has a new ERGM effort in Research, Development, Test & Evaluation (RDT&E) which is the cornerstone of its Naval Surface Fire Support (NSFS) Program. A new propelling charge, EX 167, is being designed for ERGM. The propellant planned for this charge is EX 99, the same formulation demonstrated in the CLEVER project. The Navy's new propelling charge is the vehicle to move the CLEVER process from a demonstration to a qualification and introduce this improved process into practice. Production requirements for this new charge are projected at approximately 17,000 charges or a total of 500,000 pounds of propellant for FY 2002 through FY 2009.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

The demand for fine particle size nitramines or explosive materials used in the production of propellant and plastic bonded explosives (PBX) has increased in recent years. In order to be able to meet this demand, new avenues have been explored for producing fine particle size (less than 20 micron), crystalline high-explosive materials such as RDX and HMX. The most widely used method for producing fine particle size high explosives is grinding the materials dry in a fluidized energy mill. The ground RDX is then batch mixed with the other components, typically in the presence of solvents, to produce a propellant or explosive composition for further processing. Numerous processing steps must be carried out at high cost and with significant VOC emissions, liquid wastes, and solid wastes generated to accomplish the desired result. Bofors originally developed its precipitation process to avoid dry grinding of high explosive materials. Successful demonstration of precipitating fine powders led to the exploration of other applications including powder paste feedstocks for a TSE process. In the mid 1990's, Indian Head Division, Naval Surface Warfare Center (IHDIV, NSWC) began seriously looking at alternate technologies for manufacturing the nitramine based gun propellants known as LOVA (Low Vulnerability Ammunition) with the objective of reducing VOC emissions, hazardous waste generation, and manufacturing cost. This led to a cooperative effort between IHDIV and Bofors to develop a process that would redefine the method for producing nitramine based gun propellants for the U.S. Navy. (See reference 2 for details of this development effort.)

The resulting CLEVER process is a radical departure from the old batch process that emitted VOCs to the atmosphere via evaporation. The Bofors Explosives Company in Sweden refined their closed loop process that fully dissolves all propellant ingredients into solvent. The solution is then processed through a steam precipitator that evaporates the solvent and precipitates a finely divided propellant powder. The evaporated solvent is recovered and recycled. This process is called the Bofors Precipitation Process. To transform the finely divided powder into the desired configuration for use in a gun, the precipitate is dried and then conveyed to a TSE for combination with only enough processing solvents to provide desired mechanical properties for extrusion and cutting (typically 10-13% by weight).

The new propelling charge, EX 167, being designed for the ERGM effort is shown in Figure 1. The propellant planned for this propelling charge is EX 99, a variation of M43 LOVA nitramine gun propellant used in the Army tank gun (see references 3 and 4). This formulation is the same formulation that was demonstrated in the CLEVER demonstration project. Additionally, the Navy's new EX 167 Propelling Charge was the vehicle to both demonstrate the new technology and introduce the improved process into production. Production requirements for this new charge are currently projected at 2000 charges (60,000 pounds of propellant) per year for FY 2005 through FY 2014. This equates to a total of 600,000 pounds of propellant. The other propelling charge that the Navy is currently developing is a new EX 73 Propelling Charge that uses similar hardware and propellant. Once implemented, the EX 73 Propelling Charge will be used by all 5-inch projectile types of existing Navy inventory and a planned new CARGO/ILLUM projectile. Current production requirements for the Navy's Cargo Round are also projected at 2000 rounds (60,000 pounds of propellant) per year for FY 2003 through FY 2014.

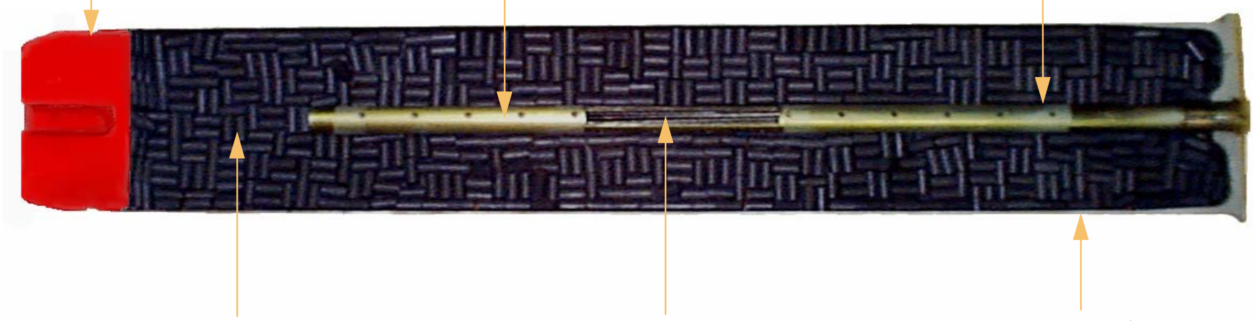

Figure 1. EX 167 Propelling Charge.

2.2 PROCESS DESCRIPTION

The CLEVER process is actually a unique marriage of the Bofors Precipitation process and continuous twin-screw processing technology. In the precipitation process, all of the propellant ingredients are charged into a tank and dissolved into a heated solvent. Bofors, which normally uses methylethylkeytone as their process solvent, modified its process to use ethyl acetate, which is a more environmentally acceptable solvent for use in the United States. The solution is then pumped to a mixing tee where it is combined with steam and water and injected into a cyclone separator. The slurry is collected in a receiving vessel that is initially filled with cold water. The downcomer from the cyclone ends below the water surface, thus creating a water seal. The precipitation continues until the dissolver is empty. The slurry is discharged in intervals into a filter neutsche where the powder is dewatered as much as possible by vacuum suction. The slurry passes through a strainer prior to the filter neutsche that removes lumps that may have formed during the process. The wet powder in the filter neutsche is transferred manually to large plastic boxes for transport to the drying facility. The cyclone overheads are condensed in a condenser. The condensate is separated into two phases, a lighter solvent phase and a heavier water phase. After the precipitation is finished, the water phase is pumped to storage a tank. The solvent phase is reused in future precipitations. The resulting propellant powder is filtered, dried, and used as a feedstock for the twin-screw extruder. The TSE process includes material feeding, twin-screw compounding/extrusion and propellant cutting to produce the final propellant grain.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

1989- Present Nobel Chemicals AB, Sweden, a branch of Bofors, applied for a patent in April 1989 for the precipitation process for the manufacture of fine particle explosive substances. Bofors has produced nitramine gun propellants for the Swedish defense department since the early 1990s and continues to improve its process.

1990 - 1993 Live twin-screw processing of LOVA nitramine gun propellant began at IHDIV, NSWC in May 1990. The approach of the initial live processing work was purely an engineering approach with the goals to learn both the operation of all of the equipment involved and how to process live material safely on a TSE. LOVA was the vehicle chosen to accomplish this task. Forty processing trials yielded over 500 pounds of live LOVA gun propellant (see reference 5). These trials used a LOVA preblend manufactured by the old method (vertical mixer). Additionally, a rheological study of a high-energy LOVA propellant as processed on the TSE was conducted with the use of an on-line, adjustable gap rheometer.

1995-1996 Bofors manufactured test lots of several variants of XM-39 LOVA gun propellant for evaluation at IHDIV, NSWC. These trials were the vehicle for learning how to incorporate nitroplasticizers into the process and substitute ethyl acetate for methylethylketone as the process solvent.

1995 - 1996 IHDIV, NSWC manufactured a LOVA gun propellant demonstration lot. The objective was to test a lot of M43 nitramine gun propellant manufactured in the TSE and compare the test results to those obtained from the batch processed propellant. The TSE feed material was prepared in a manner similar to the Bofors Precipitation Process; however, ground RDX was the starting material. The propellant grains were successfully extruded and test fired (see reference 6).

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The CLEVER process could be used to produce all of the propellant for the new generation 5"/54 gun ammunition. The use of the CLEVER process would result in a 47% reduction of VOC emissions with a 41% cost savings. These reductions could be achieved at the two current active gun propellant manufacturing facilities - IHDIV and the Radford Army Ammunition Plant (RAAP). In addition to the gun propellant production base, the closed loop Bofors Precipitation Process has potential in explosive production processes. Although this program was not geared toward demonstrating the viability of explosive processing, it has provided an important "next step" in bringing the technology to the U.S. so that its full pollution prevention and efficiency benefits can be examined. CLEVER's current limitations are the lack of a large scale continuous processing facility dedicated to energetics and a Bofors precipitation plant in the U.S. Both limitations are being addressed by construction of dedicated facilities at IHDIV, NSWC.

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3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The primary performance objective was the reduction of emissions and waste realized as a result of replacing the conventional process with the CLEVER process. A summary of the performance objectives is shown in Table 1.

Table 1. Performance Objectives.

Performance Objectives	Acceptable Target	Objective Met?
VOC Reduction	40%	Yes
Waste Reduction	10%	Yes
Ballistic Performance	Comparable to or better than conventional propellent	Yes
Safety Performance	Comparable to or better than conventional propellent	Yes

Emission reduction was verified through a validated material balance as was performed for standard batch processed LOVA (see reference 8 for details).

Input + Generation - Output - Consumption = Accumulation

Similar material balances for each operation in the CLEVER process were performed as shown in Figure 2.

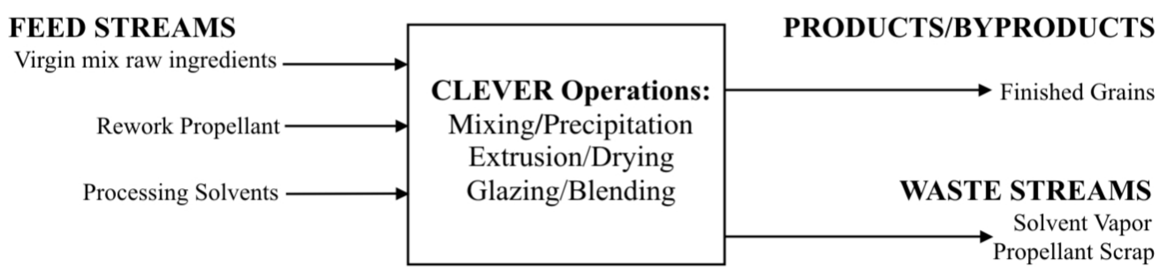

Figure 2. Material Balance for CLEVER.

Each appropriate stream was chemically analyzed to verify if fugitive emissions exist. At both demonstration sites, waste streams were collected, analyzed, and measured to determine the waste quantities at the different locations.

A second objective of this project was to demonstrate that the new, cost efficient and environmentally friendly CLEVER process could produce an acceptable gun propellant. Acceptability for a gun propellant is determined by its ballistic and safety performance. The ERGM program is currently qualifying the EX-99 propellant formulation. A propellant specification (reference 4) has been prepared for the ERGM program. This specification and the baseline data established by the ERGM program were used to determine acceptable propellant (see section 3.6, Table 2). Additionally, as discussed previously, the EX-99 propellant formulation is very similar to the M43 propellant formulation that was produced at IHDIV, NSWC for several years. All of this data was also available for comparison purposes.

3.2 SELECTION OF TEST FACILITIES

The propellant paste was made by Bofors in Karlskoga, Sweden using their precipitation process. The paste was then transported to IHDIV, NSWC and extruded by the TSE process. Environmental impacts of CLEVER were then compared to existing data from the conventional process for the manufacture of nitramine gun propellant. Both CLEVER and conventionally processed propellant were loaded into propelling charges and ballistically evaluated at Dahlgren Division (DD), NSWC to determine whether the two processes produced similar results in actual end use.

3.2.1 Bofors, Sweden Facility

At the beginning of the CLEVER project, Bofors AB consisted of the parent company with four divisions, several Swedish subsidiary companies, as well as sales companies and representatives in some 40 countries throughout the world. Since that time, Bofors AB has gone through a series of restructurings. The Bofors business concept to develop, manufacture, market and maintain advanced material for the Swedish Defense Forces and the international market, as well as to apply its technologies to other projects within its sphere of competence, remains unchanged. Bofors, the company that developed the precipitation process and holds the patent rights, was the logical choice to manufacture the EX-99 powder for use in the demonstration. Many products are made for both military and commercial use. Commercial products cover about 50% of sales. The company has made great advances in the development of insensitive munitions, such as LOVA propellant and PBX. LOVA is also used in vehicle safety applications such as airbags. The number of employees is approximately 100. To have licensed their process and built a plant in the U.S. to produce the limited amount of powder required for the demonstration would have been prohibitively expensive.

3.2.2 Indian Head Division, NSWC

IHDIV, NSWC, established in 1890 as the Naval Proving Ground, is the oldest, continuously operating naval ordnance facility in the United States. IHDIV, NSWC is located on a peninsula bordered by the Mattawoman Creek and the Potomac River in Charles County, Maryland. The activity consists of 1,600 buildings, 3,500 acres, and approximately 2,000 employees. The total plant asset value is $1.5 billion with over $50 million invested in the last five years in environmental efforts.

In addition to being the Navy's leader in continuous twin-screw processing of energetics, IHDIV, NSWC carries out a full spectrum of functions for energetics research, development, manufacturing and in-service engineering. This activity possesses the unique capability to transition all energetics from laboratory to production and then to fielded product. The scope of capabilities at IHDIV, NSWC allows for efficient use of specialized expertise and expensive facilities required for research and development, scale-up, manufacture and testing of energetics.

3.2.3 Dahlgren Division, NSWC

Since 1918, the Navy-maintained shore station to test ordnance materials has been located at Dahlgren, Virginia. DD, NSWC's mission is to conduct a comprehensive program of warfare analysis, research, development, test, evaluation, system integration and fleet engineering support for surface warfare and related fields of technology. The facility consists of 4,400 acres of land including a 2,000-meter land range that has recently been added to accommodate Army and Marine Corps testing requirements and an instrumented water range 25 miles long and 5 miles wide. This complex is equipped with gun emplacements for firing all naval guns for: (1) acceptance testing of guns and ammunition components (propellants, cases, primers, projectiles, barrels, and oscillating assemblies); and (2) proof of gun propellants to determine the type and weight to be used for any gun and projectile combination. Uniformity of propellant performance is determined by the measurement of projectile ejection time, projectile initial velocity, projectile water-impact range, and gun chamber pressure-time history. Support capabilities include fabrication shops, temperature conditioning of explosive items, projectile and propellant charge assembly, gun component maintenance and electronic, and optical instrumentation. Currently, qualification of the ERGM round with EX 99 propellant is being pursued by the Navy at DD, NSWC.

3.3 TEST FACILITY HISTORY

IHDIV, NSWC was selected as the test site for the CLEVER demonstration based on its experience in the production of gun propellants. Over one million pounds of M43 LOVA nitramine gun propellant was produced in the early 1990's using the conventional batch process, and extensive data on solvent emissions and scrap generation rates for this process were gathered and documented. Specifics are available in a technical report Indian Head Technical Report (IHTR) 1814 that summarizes the life cycle aspects of conventional processing of M43 nitramine gun propellant. Additionally, IHDIV, NSWC had processing experience with twin-screw extruders dating back to 1985 and had successfully processed limited quantities of LOVA propellants using their 40-mm twin-screw extruder. Finally, IHDIV, NSWC is currently the Navy's only ongoing production base for nitramine gun propellants.

3.4 PHYSICAL SET-UP AND OPERATION

The duration of the CLEVER demonstration, which ran from the fall of 1997 until the spring of 2000, was largely due to the complexity of the process changes required. The CLEVER process cannot be described in terms of modifications to the existing batch production process and facilities. CLEVER is best described as a complete reengineering of the way nitramine gun propellants are manufactured. The proof of concept work conducted prior to the CLEVER project addressed the initial concerns of process feasibility and development. The lessons learned from previous manufacturing experience were used to improve the pre-demonstration process design, equipment set up, and operation. The result was a conceptual design for a technique for the manufacture of the demonstration propellant as well as for constructing a facility for the manufacture of both low rate initial production (LRIP) quantities and large-scale production quantities at a United States location. Several United States representatives spent time in Sweden learning the process "first hand," which facilitated design change considerations utilizing the existing process equipment. Swedish representatives spent a similar amount of time in the United States to assess the process technology currently used and proposed locations for plant construction. Both exchanges were critical to the definition of the methods and equipment needed to establish the transfer of this Swedish technology to the United States.

3.4.1 Precipitation Process Reconfiguration

The Bofors Precipitation Process, as operated at their Karlskoga facility, normally uses methylethylketone (MEK) as the solvent to dissolve propellant ingredients. Because of environmental concerns, there is a requirement to use an alternative solvent as the processing solvent. Ethyl acetate was chosen as the alternative solvent. The use of ethyl acetate in place of MEK required Bofors to operate their plant at a lower capacity than normal because the ingredients are less soluble in ethyl acetate. Also, the specific LOVA formulation (EX 99) required different ingredients than those which Bofors normally uses to manufacture their LOVA formulations. First, it required a different grade of Cellulose Acetate Butyrate (CAB) than Bofors uses, CAB 381-20 instead of CAB 171-15. Second, it required Acetal/Formal (A/F) as an energetic plasticizer versus the typical non-energetic plasticizer that Bofors uses, Acetal Triethyl Citrate (ATEC). These formulation changes produced a somewhat stickier paste than Bofors was accustomed to handling. As a result, modifications were made to how the precipitator and cyclone separator were operated in order to prevent clogging. However, no structural changes to the plant were required for the CLEVER demonstration. (See reference 8 for details of this work.)

3.4.2 Twin-Screw Extruder Process Reconfiguration

Prior to the CLEVER project, the twin-screw processing efforts on LOVA formulations at IHDIV, NSWC were geared towards understanding the process as well as the process parameters required to safely obtain good mixing and a high quality product. The emphasis was not on waste minimization during this early work. Meeting the CLEVER project objectives of minimizing the generation of scrap and emissions while maximizing the yield of good material necessitated both remotely refilling the solid feeder while operating the extruder and pelletizing the extruded strand on-line into the final propellant grains. Accomplishing these two process changes required a substantial redesign of the refill hoppers and the development of new automatic and remote strand handling, pelletizing and product collection equipment. The cohesive nature of the EX 99 powder caused considerable problems during refill due to bridging in the overhead refill cylinders. The refill cylinders were modified to add radial breaker bars to the plunger shaft. This modification, as well as cycling the plunger up and down during refill, solved the bridging problem.

As stated previously, on-line pelletizing was the second challenge faced at the IHDIV, NSWC facility. Bofors' uses an attended operation to pelletize their LOVA propellants. While LOVA propellant strands are routinely pelletized as an attended operation at IHDIV, NSWC, the cutting operation is done at a separate area away from the mixers and presses for safety reasons. According to safety regulations, the minimum distance between the IHDIV, NSWC extruder, when processing a Class 1.1 material and an attended operation, is 300 feet. This regulation clearly precluded using Bofors' method of pelletizing (also IHDIV, NSWC's batch method of pelletizing) without a major design effort to develop a new pelletizing machine that would be self-threading and remotely adjusting.

The approach to pelletizing (or cutting) on-line was as follows. Once the extruder was at steady state and the observed strand quality was good, a guillotine cutter was activated to cut the two propellant strands off flush at the die face while simultaneously aligning a set of four-foot Teflon tubes with the die face. The strands were guided into the tubes via a funnel block, which also added water at the rate of a one-half liter per minute per tube. This water flow lowered the strand drag and cooled the propellant strands so they could be cut. On exiting the Teflon tubes, each propellant strand was cut to a length of 30 inches and dropped onto the feed belts of a constantly running Nobel Chematur short cutting machine (i.e., pelletizer). The entire strand conveying and pelletizing system was mounted in a tank so that the water used to convey and cool the strands could be recycled. The set-up used is depicted in Figure 3.

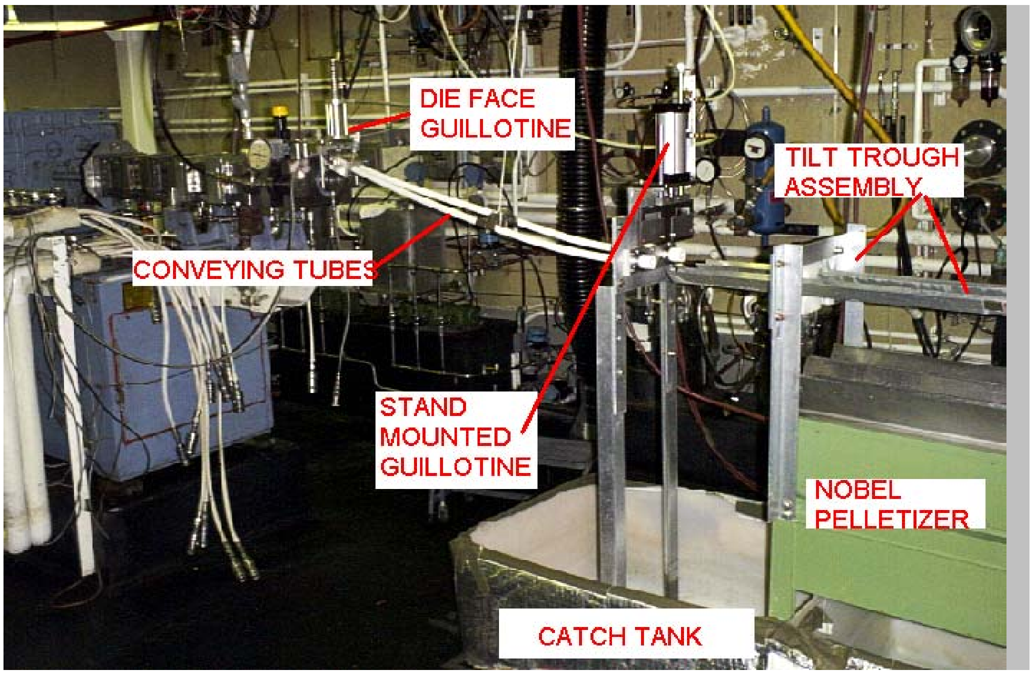

Figure 3. LOVA Twin-Screw Extrusion and Pelletizing Equipment Set-Up.

Based on experience gained during the demonstration, a new second-generation strand handling and pelletizing machine capable of handling multiple continuous strands was designed. A four-strand system has been successfully demonstrated using the 40-mm extruder, and an eight-strand system is being installed in the new 88-mm extruder facility.

3.5 SAMPLING AND MONITORING PROCEDURES

Sampling and monitoring was in accordance with the Environmental Security Technology Certification Program (ESTCP) CLEVER Technology Demonstration Plan (reference 8) except for the following changes. The original plan was to measure the solvent loss into the processing bay air; however, this proved to be impractical since the building has a once through ventilation system with a complete air change every 6 minutes which results in extremely low solvent concentrations. Tracking the weight of powder paste refilled to the loss in weight feeder at each refill also proved to be difficult. The vibrators on the individual refill cylinders occasionally malfunctioned. The malfunctions resulted in incomplete emptying of the refill cylinders, and those cylinders had to be cycled multiple times, thus making a running tally inaccurate. Calculating the weight fed from the loss in weight feeder set point and run times proved to be a more reliable and accurate method. The plan was to individually collect and weigh the material from each ramp up and ramp down based on the assumption that there would be one ramp up and ramp down per run. Because of the mechanical difficulties experienced, the material from multiple starts and stops was commingled in the collection container along with some water leakage from the strand conveying tubes. Feeder data was also used to compute the ramp up and ramp down quantities.

3.6 TESTING

The safety and small-scale sensitivity tests were conducted on paste samples from Batch 484/98. Safety characterization of Batch 484/98 was considered to be representative of all three batches. All other paste tests were conducted on all three paste batches. Similarly, grain testing was conducted on Lot IH94000E-EX99-0088, which consisted of the most material and was considered representative of both lots. Final performance evaluation (i.e., gun firings) was conducted on both grain lots. The tests performed on the CLEVER propellant grains were also performed on propellant grains manufactured by the conventional batch process. The test matrix used to verify acceptable performance of the product produced by the CLEVER process is presented in Table 2 with the following exceptions: Paste Test #7, Deflagration-to-Detonation Transition (DDT) testing was not done. The rationale for not doing this testing was that the other safety and small-scale sensitivity tests characterized the paste material as Class 1.1, thus making this test moot. The test matrix was developed by the CLEVER Integrated Product Team (IPT) and documented both by the minutes of the IPT meeting as well as the CLEVER Technology Demonstration Plan (reference 8).

Table 2a. Propellant Paste Test Matrix.

PASTE TESTS	PROCEDURE See Relevant Section of the Final Report (Reference 10)	TEST SITE
1. Past Chemical Composition*	Section 4.4.1.1	Bofors, Sweden
2. Thermal Stability - Differential Scanning Calorimetry (DSC)*	Section 4.4.1.2	IHDIV, NSWC
3. Microtrac Analysis for RDX Particle Size Distribution**; Malvern Analysis for Particle Size	Section 4.4.1.3	IHDIV, NSWC; Bofors, Sweden
4. Microscopic Analysis (for free RDX)*	Section 4.4.1.4	IHDIV, NSWC
5. Safety Testing: Impact, Friction, and Electrostatic Discharge*	Section 4.4.1.5; SOP P60028, P60029 and P60030	IHDIV, NSWC
6. Small Scale Shock Sensitivity: Cap Test and Card Gap Test*	Section 4.4.1.6; NAVSEA Inst 8020.8A	IHDIV, NSWC
7. Deflagration-to-Detonation Transition (DDT) Testing	Test not completed. See Section 4.3.2	IHDIV, NSWC

* - CLEVER processed material only
** - Batch processed material only

Table 2b. Propellant Grain Test Matrix.

PROPELLANT GRAIN TESTS	PROCEDURE See Relevant Section of the Final Report (Reference 10)	TEST SITE
1. Safety Testing: Impact, Friction, and Electrostatic Discharge*	Section 4.4.2.1; SOPs P60028, P60029 and P60030	IHDIV, NSWC
2. Small Scale Shock Sensitivity: Cap Test, Card Gap Test and Unconfined Burning Test*	Section 4.4.2.2; Chapter 5 NAVSEA Inst 8020.8A	IHDIV, NSWC
3. Ballastic Impact Chamber (BIC) Test*	Section 4.4.2.3	IHDIV, NSWC
4. High Rate Mechanical Properties*	Section 4.4.2.4	Army Research Laboratory (ARL)
5. Dimensional Analysis of Finished Grains	Section 4.4.2.5; MIL-STD-286C, Method 504.1.1 or Method 504.6.1	IHDIV, NSWC
6. Scanning Electron Microscopic (SEM) Analysis*	Section 4.4.2.6	IHDIV, NSWC
7. Heat of Explosion	Section 4.4.2.7; MIL-STD-286C, Method 802.1	IHDIV, NSWC
8. Propellant Density	Section 4.4.2.8; MIL-STD 286C, Method 510.3.1	IHDIV, NSWC
9. Propellant Chemical Composition: CAB/NC, RDX/HMX, EC, A/F	Section 4.4.2.9; MIL-DTL-82965 (OS)A, Section 4.6.1	IHDIV, NSWC
10. Variable Confinement Cook-off Test (VCCT)*	Section 4.4.2.10	IHDIV, NSWC
11. Wide Angle X-Ray Diffraction (WA-XRD) for Degree of Mixedness*	Section 4.4.2.11	Steven's Institute of Technology
12. Closed Bomb Burn Rate (High Pressure)	Section 4.4.2.12; MIL-STD-286C, Method 8-1.1.2	IHDIV, NSWC
13. Gun Firing	Section 4.4.2.13	Dahlgren Division, NSWC

* - CLEVER processed material only
** - Batch processed material only

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4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

The performance objectives of the demonstration were met, as summarized in Table 3.

Table 3. Demonstration Performance Objectives.

Performance Objective	Objective Met?
VOC Reduction	Yes
Waste Reduction	Yes
Ballistic Performance Comparable to or Better than Conventional Propellant	Yes
Ballistic Performance Comparable to or Better than Conventional Propellant	Yes

Refer to the CLEVER Final Technical Report (reference 10) for the details of the demonstration as well as data collected and evaluated.

4.1.1 VOC Reduction

The CLEVER process demonstrated a total VOC emissions rate of 0.257 lb/lb of LOVA (the product), 0.103 lb/lb of LOVA for the Bofors process, and 0.154 lb/lb of LOVA for the subsequent twin screw processing and grain finishing operations.

4.1.2 Waste Reduction

The scrap generation for the CLEVER process is as follows. The demonstrated waste generation rate for the precipitation process is 0.058 lb/lb of LOVA. During the twin-screw processing, cleanup data was only available for the second run since the first was terminated by the extruder jam. Based on the second run, 7 pounds of scrap were generated, consisting of a combination of oatmeal and solvent (used to purge the extruder), LOVA propellant, and rags. On a per pound basis, the scrap generated during this run amounted to 0.024 lb/lb of LOVA for a total of 0.082 lb/lb of LOVA for the CLEVER process.

4.1.3 Ballistic Performance

The performance of the CLEVER produced propellant in the 5” gun met or exceeded all requirements. Overall, the twin-screw processed EX 99 propellant met expectations by consistently producing 18 MJ of energy while remaining at or below 65,000 psi with a charge weight of 26 pounds. This charge weight just filled the available cartridge case volume. For this particular test application (110 lb Hijack projectile seated at a nominal 37.8” seating distance), the granulation was nearly optimum. According to the pressure-time plots, Lot 89 seemed to reach a higher pressure and burn slightly faster, which was more efficient than Lot 88.

The following differences in processing history were noted.

- Two different Bofors paste batches were used to make grain lots IH94000E-EX99-0088 & IH94000E-EX99-0089.

- One production run had mechanical issues, which caused it to shut down several times. Even though the muzzle velocity seemed to have a large overall standard deviation compared to the other parameters, it is within previous EX 99 batch processed results. The standard deviation for the individual lots was very good, and if these lots were blended, which is normal practice, the standard deviation would be reduced.

The ejection time varied considerably. This is most likely due to the inconsistency currently seen with the EX170 primers. IHDIV, NSWC is researching this issue and is trying to solve the problem with various modifications to the existing configuration.

The gas blowback along the cartridge cases for these firings is consistent with previous results. The gun barrel thermal data for the CLEVER processed propellant is consistent with the batch processed propellant.

4.1.4 Safety Performance

There is virtually no difference in safety characteristics between LOVA manufactured by the CLEVER or the batch processes.

4.2 PERFORMANCE CRITERIA

There were no changes or deviations to the performance criteria established in the CLEVER Technology Demonstration plan (reference 8). See Section 3.6, Table 2 for a summary of the performance tests conducted.

4.3 DATA EVALUATION

CLEVER processed grains were equal to or superior to batch processed grains in all respects with some qualification. The CLEVER grains were made using brand new die tooling that was subjected to minimal wear and tear during the demonstration as compared to what production tooling generally experiences. Bofors did an excellent job of manufacturing the test batches, though it did encounter significant processing problems that were solved on the fly. The yield and mass balance data are averages of only the last two batches, which do not represent a process that was fine tuned over an extended production run. IHDIV, NSWC experienced similar problems during the twin-screw extruder processing. The heart of the twin-screw technology, the extruder, worked flawlessly, but the strand conveying and cutting system was plagued with mechanical problems. This equipment had been developed and tested during relatively short runs and was found lacking when it came to running for 10 hours without maintenance. As a result, there was a lot of unplanned down time with multiple starts and stops during the first run. It was not until the second run that mass balance data representative of normal operations was obtained.

4.4 TECHNOLOGY COMPARISON

The only competing technology to the CLEVER process is the current batch LOVA production process. These two processes can be compared in five main areas: propellant grain quality, process yield, solvent emissions, scrap generation, and complexity. These areas are discussed in the following sections.

4.4.1 Quality

The quality of LOVA grains manufactured by the CLEVER process was equal to or better than batch processed grains in all areas. The uniformity of the three paste batches produced by the Bofors Precipitation Process was particularly encouraging considering that these were the first three batches made with this particular LOVA formulation and solvent. The fact that the paste varied little as Bofors changed process parameters to solve the adhesion problem shows the process is robust and tolerant of upsets.

4.4.2 Process Yield

The best way to compare the two process yields is to look at the respective rework rates. The batch process has two main sources of rework material, which must be cycled back into a dedicated rework mix where it is resolvated. The first source is the batch pressing operation during which the propellant is extruded into strands of the proper geometry. On average, 7.6% of a mix cannot be extruded and is retained as press heels, which are reprocessed in a rework mix. The strands are then conveyed to a pelletizing operation where they are cut into grains. Typically an additional 10.4% of the mix is rejected at this point because the perforations are off center or the strands are damaged or have dried out to the point they can not be cut. These reject strands are also recycled into a rework mix. This gives a combined rework rate of 18% for the batch process. The CLEVER process rework rate during the demonstration was 13.5%, as compared to a batch rate of 18%. Given that there is a lot of room for improvement, the rework rate is expected to decrease to less than 6% in production as experience is gained with the CLEVER process.

4.4.3 Solvent Emissions

The batch process emits 0.387 pounds of solvent per pound of propellant made. The first part of the CLEVER process, the Bofors Precipitation Process, emitted 0.103 pounds of ethyl acetate per pound of LOVA paste. At steady state, the twin-screw process used 0.136 pounds of mixed solvent, 70/30 ethyl acetate/ethanol blend, per pound of LOVA. When this ratio is adjusted for solvent used during the ramp up and ramp down, it increases to 0.154 pounds of solvent emissions per pound of LOVA. The total solvent emission for the CLEVER process as demonstrated was 0.253 pounds of VOCs per pound of LOVA. This represents a 35% decrease over the conventional batch process. If Bofors' projection of 6% emissions proves true in production and the rework rate at the twin-screw extruder can be reduced to 4%, which seems feasible, the projected VOC emissions decrease to 0.204 pounds per pound LOVA. This decrease would increase the reduction in VOC emissions to 47%.

The conventional batch process, without the thermal catalytic incineration system (TCIS), was used for this comparison. The baseline emissions data was developed during the production of approximately three million pounds of LOVA nitramine gun propellant for the Army. The TCIS was not used during this production because it was not designed and built until after the production was completed. Therefore, data using the TCIS was not included in the analysis for this project.

4.4.4 Scrap Generation

The scrap generation rate for the CLEVER demonstration (0.082 lb/lb of LOVA) was significantly higher than the batch rate of 0.032 lb/lb of LOVA. However, there is much room for improvement in the CLEVER process. If the 98% yield assumption for the precipitation process is correct, the CLEVER scrap generation rate drops to 0.044 lb/lb of paste. Furthermore, the twin-screw contribution is entirely dependent on how long it is run. For a truly continuous process, it would drop substantially because any production lot could be manufactured with minimal starts and stops. The actual waste generated at the twin-screw extruder could be reduced by 75% simply by using a split-barrel extruder design. This design eliminates the need for purging prior to final cleaning thus reducing the waste generated from 0.024 lb/lb of LOVA to 0.006 lb/lb of LOVA. An overall waste generation rate of 0.026 lb/lb of LOVA is expected for the CLEVER process when the extruder waste is combined with the projected waste from the Bofors precipitation process (0.020 lb/lb of LOVA). This expected waste generation rate translates into an 18% reduction in waste when compared to the conventional technology.

4.4.5 Process Complexity

The batch process is fairly complex involving seven operations verses four for the CLEVER process. Additionally, the batch operations are coupled in time and must be performed sequentially. The Bofors Precipitation Process makes the feedstock for the twin-screw extruder. The feedstock can be made ahead of time and stockpiled until the extruder is ready to run. Also, since the RDX no longer needs to be ground, another variable that can affect quality is eliminated while safety is enhanced. The fact that the processes are decoupled with respect to time provides the flexibility of running them concurrently, if maximum yearly output is required, or sequentially with the same crew to cut labor requirements for smaller quantities.

Overall, the CLEVER process has less unit operations and is a simpler and more robust process than the batch process. Additional advantages are less capital investment in facilities, a smaller facilities footprint, and enhanced flexibility.

5.0 COST ASSESSMENT

5.1 COST REPORTING

An essential criterion for evaluating ESTCP programs is the program's affordability. This section presents the detailed cost assumptions and estimates for both Batch and CLEVER processes, consistent with the Environmental Cost Analysis Methodology (ECAM) (see references 11 and 12) and validated by using the P2/Finance software. The detailed analysis presenting assumptions, life cycle estimates, environmental comparison and cost comparison can be found in Appendix B of the CLEVER Final Technical Report (reference 10).

The cost analysis captures (1) the investment cost for EX 99 CLEVER propellant production, (2) the direct EX 99 propellant production cost, and (3) direct production support activities. The results from the cost analysis were used in a cost effectiveness analysis to determine the net present value (NPV), internal rate of return (IRR), and payback period. It should be noted that the CLEVER cost estimate should not be interpreted as the total ownership cost (TOC) of production. The CLEVER cost estimate is not a TOC estimate because it only addresses part of the design and development effort and the production costs. The CLEVER estimate does not include the cost of monitoring and testing after deployment, nor does it estimate the disposal cost. The cost estimate is based on input from production experts, process experts, and extrapolation of production data.

5.2 COST ANALYSIS

The assumptions in Table 4 are the result of interviews with the technical people involved in the CLEVER project. These program assumptions establish a general framework to make an equitable cost and environmental comparison between the Batch process and CLEVER process. (Information used to generate the production quantity can be found in references 9 and 10.)

Table 4. Project Assumptions for Cost Analysis.

Description	Value	Data Description/Source
Fiscal Year (FY)	2000	All cost estimate values are based in constant year FY 2000 dollars.
Period of Performance	10 Years	The Batch/Clever process analyses are over a 10-year period of performance.
Discount Rate (Real)	4.0%	OMB Circular A-94, Revised January 2000
Annual Production Quantity (pounds)	250,000	Comparison quantity of EX-99 propellant.

The formulation (raw materials) to produce EX 99 propellant is presented in Table 5.

Table 5. EX 99 Propellant Material/Formulation.

Ingredients	Percentage
RDX	76.0%
Cellulose Acetate Butyrate (CAB)	12.0%
Acetal/Formal (A/F)	7.6%
Nitrocellulose (NC)	4.0%
Ethyl Centralite (EC)	0.4%

5.2.1 Cost Summary

The CLEVER Cost Summary is presented in Table 6. Utility resource consumption and costs may be a significant cost driver in evaluating alternative manufacturing technologies. Utility analysis consisted of reviewing data for resource consumption from Batch and CLEVER technical reports. The Batch process relies primarily on electricity, while the CLEVER process requires electricity, steam, and water. Preliminary analysis of the utility consumption for each process revealed that this cost is negligible to the overall cost analysis.

Table 6. CLEVER Cost Summary.

CLEVER Cost Summary					
Direct Start-Up Cost		Direct Operations & Maintenance Cost (10 year estimate)		Indirect Environmental Activity Cost (10 year estimate)	
Actvity	Dollars	Actvity	Dollars	Actvity	Dollars
Capital Equiment	$ 14,247,472	**Operations Labor**	$23,821,080	**Environmental Office**	$ 2,068,976
Twin Screw Extruder	$ 2,585,000	**Supervision/Technical Support**	$ 4,550,750	**Permitting**	$ 77,000
Bofor Precipitation Process	$ 11,652,600	**Maintenance**	$ 1,626,330	**Testing/Monitoring**	$ 13,990
Solvent (11,894 pounds)	$ 9,872	**Raw Material**	$29,574,420		
Site Preparation & Construc	$ 5,502,000	**Processing Material**	$ 395,870		
Planning/Engineering	$ 563,000	**Waste Disposal**	$ 379,470		
Planning	$ 370,448	**Other Direct Cost**	$ 1,250,000		
Permitting	$ 12,000				
Total Investment	**$ 20,694,920**	**Total Operations & Maintenance**	**$61,597,920**		**$ 2,159,966**
All Costs are Presented in Constant Year 2000 Dollars					
Environmental Office Activities include: Compliance Audits, Document Management, Envr. Mgmt. Plan, Reporting Requirements					
Permitting Activities includes obtaining State and Federal, Air, Hazardous Waste and Waste Water permits					

The CLEVER production process will require a capital investment for the following.

- The Bofors Precipitation Process equipment.
- Construction of a new production facility. (The total cost estimate for construction of the new processing facility is $11.0 million, split evenly between the EX-99 propellant production and other energetic material production programs.)

- The 92mm Twin-Screw Extruder (TSE). (The total cost estimate for the TSE is $5.2 million, split evenly between the EX-99 propellant production and other energetic material production programs.)

In addition to the equipment capital investment, additional investment requirements include:

- The CLEVER/ESTCP demonstration and validation effort,
- The review and development of standard operating procedures (SOP), and
- The initial environmental assessment, permitting and testing.

The production cost estimate is based on an analysis of current production processes and an impact analysis of how the CLEVER production process will reduce cost and the generation of waste streams.

5.3 COST COMPARISON TO CONVENTIONAL TECHNOLOGY

Please refer to Appendix B of the CLEVER Final Technical Report (reference 10) for the detailed cost comparison contained in the Closed Loop Energetics with VOC Emission Reduction (CLEVER) Cost and Environmental Analysis. The results presented in this analysis are summarized below.

The cost comparison compares the baseline Batch process to the CLEVER process in terms of net present value (NPV), internal rate of return (IRR) and payback period. Each one of these measures helps the decision-maker with the investment decision. The financial analysis is based on production of 250,000 pounds of EX-99 propellant per year, over 15 years.

5.3.1 Net Present Value

The NPV is the present value of the future net revenues or cost savings of an investment less the investment's current and future cost. An investment is profitable if the NPV of the net revenues it generates in the future exceeds its cost (e.g., a positive NPV). The NPV method is based upon the concept that a dollar today is worth more than a dollar tomorrow. The methodology, using a Discount Rate[1], progressively reduces the value of costs and revenues over time. Federal facilities typically use the discount rate published by the Office of Management and Budget (OMB).

The NPV of the CLEVER cost analysis is $16.1 million (Table 7). This is calculated by estimating 10 years of cost for producing 250,000 pounds of EX 99 propellant per year and the investment cost for the CLEVER process. The 10-year cash flow is then discounted at the real OMB rate of 4.0% per year and summarized.

[1] Discount Rate: The interest rate used to discount future cash flows to their present value. This represents the rate of return that could be earned by investing in a project with risks comparable to the project being considered. Federal facilities generally use a discount rate determined by the Office of Management and Budget (OMB).

Table 7. Net Present Value.

	Investment Cost	10 Year Cost Estimate Constant Year	Total Cost Estimate	Present Value Total Cost Estimate (Discount Rate 4.0%)
Batch Process	$ 0	$109,011,742	$109,011,742	$88,418,288
CLEVER Process	$20,694,920	$ 63,757,886	$ 84,452,806	$72,408,277
NPV				**$16,010,011**

5.3.2 Internal Rate of Return

While the IRR is not commonly applied in federal investment decision making, it has been estimated for one more point of reference. The purpose of the IRR calculation is to determine the interest rate at which the NPV is equal to zero. If the IRR exceeds the "hurdle rate" (defined as the minimum acceptable rate of return on a project), the investment may be deemed worthy of funding.

The estimated 10-year IRR for the CLEVER process (Table 8) is 17.5%.

Table 8. Internal Rate of Return.

	Internal Rate of Return (10 year)
CLEVER Process	17.5%

Because the IRR (17.5%) is greater than the discount rate (4.0%), this financial metric supports the decision to invest and implement the CLEVER process.

5.3.3 Discounted Payback Period

The discounted payback period analysis is the investment performance indicator most commonly used by many federal agencies (see reference 13). The purpose of a discounted payback analysis is to determine the length of time required for the discounted future savings of a project to repay the investment costs. Those investments that recoup their costs before a set "threshold" period are usually determined to be worth funding. The estimated discounted payback period is approximately 5.15 years (Table 9). The acceptability of this time frame should be considered by the decision-maker.

Table 9. Discounted Payback Period.

	Discounted Payback Period
CLEVER Process	5.15 Years

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

Early in the demonstration several twin-screw extruder trials were done using the same screw profile and barrel configuration that had been successfully used during the IHDIV, NSWC 1996 LOVA work. Post run inspection of the extruder barrel bore found abnormal wear patterns resulting from hard contact between the screw and barrel wall. The resulting engineering investigation and implementation of corrective actions delayed the program by a year and increased cost by $100,000. An extensive design of experiment (DOE) was conducted using various extruder screw configurations and operating parameters to determine operating conditions that would adequately mix the LOVA and avoid the maintenance and safety concerns associated with hard metal-to-metal contact within the extruder. Replacement of damaged barrel sections and purchase of additional Bofors powder for the DOE cost approximately $25,000, with an additional $75,000 of labor for conducting the DOE, lab tests, and engineering.

6.2 PERFORMANCE OBSERVATIONS

The LOVA propellant manufactured by the CLEVER process met all performance requirements for the new EX 167 propelling charge for the Navy's 5" gun. The process also demonstrated substantial reductions in VOC emissions and hazardous solid waste generation. The capability of the process to recycle or rework material was not demonstrated. The cost and logistics of shipping nonconforming material resulting from ramp up or shut down of the extruder back to Bofors for incorporation into a special run to demonstrate the ability to recycle or rework material was prohibitive. However, the capability of the process to handle rework is well documented since Bofors does this on a regular basis when they produce XM-39 LOVA propellant.

6.3 SCALE-UP

Scale-up of the CLEVER process has to be looked at as two distinct processes. The heart of the Bofors precipitation process is the precipitator/cyclone, which is a licensed proprietary technology. This unit is designed with a fixed single shift throughput of 100,000 pounds per year. Scaling plant capacity is easily done in multiples of 100,000 pounds by a combination of adding additional cyclones to be run in parallel and increasing the number of shifts per day. Scaling up the equipment that supports the precipitator/cyclones, such as the dissolver tanks, condensers, solvent recovery columns and filters, etc. is a straightforward unit operations exercise. The second process involves the twin-screw extruder, extrusion die and on-line pelletizer combination. The extruder throughput (pounds per hour) scales approximately as the ratio of the cube of the screw diameters. The technically challenging scale-up problem lies in the design of the die. As an example, the CLEVER demonstration extrusion trials were done on a 40-mm twin-screw extruder at a throughput of 30 lbs/hr using a two-strand die. An 88-mm extruder operating at comparable conditions including linear strand extrusion speed would require a 21-strand die and integrated strand handling and cutting equipment, which is an extremely complex design problem. The problem can be simplified to an extent by increasing the linear strand extrusion speed. However, there is an upper limit to the strand speed, which is dependent on the materials rheology and the design limits of the remote strand handling and cutting equipment currently available. Bofors has successfully designed and used a four-strand die for the production of LOVA nitramine gun propellants and IHDIV, NSWC has developed and tested a remotely operated four-strand cutter. IHDIV, NSWC has designed and procured an integrated eight-strand die and strand cutting system that is scheduled to be installed in its new Continuous Processing Scale-Up Facility in the summer of 2002 for evaluation.

6.4 OTHER SIGNIFICANT OBSERVATIONS

The Bofors Precipitation Process, as operated in Sweden for the CLEVER demonstration, uses significant quantities of both contact process water and non-contact cooling water, which Bofors is allowed to discharge directly to outfalls. A modified process and plant design will be required for use in the United States. As part of ongoing efforts at IHDIV, NSWC to demonstrate and scale-up continuous processing technology, a prototype precipitation plant is being built. The design of this plant will include the recycling and reuse of both contact process water and non-contact cooling water. Operation of this plant, scheduled for FY 2004, will demonstrate that the process can be modified to be compliant with U.S. environmental requirements.

6.5 LESSONS LEARNED

The CLEVER process demonstration is complete, and the facilities required to implement it on an industrial scale are currently being built. While the learning process continues, several pertinent lessons were learned, which may be of value to anyone considering implementing this technology on an industrial scale. The precipitation process itself is still an evolving technology. If the planned product differs significantly from the LOVA formulations, which form the current experience base, a small-scale demonstration of the precipitation process is highly recommended. Having engineering personnel closely involved with the actual production of demonstration lots at the Bofors facility resulted in a practical understanding of the process. This understanding proved to be essential when it came time to transition from a demonstration phase to an actual design and build program. These plants are not yet turn-key installations, so a close working relationship between Bofors, who supplies the technology, the A&E firm responsible for the design, the construction contractor, and the customer's engineering department, is essential.

When developing an implementation plan and schedule, major emphasis should be placed on the selection or design of product handling equipment such as on-line cutters, product takeaway, and refill equipment required for the twin-screw extruder portion of the process. The unique requirements of energetic materials continuous processing increases the complexity of the equipment, and many current designs used in batch explosive plants or industry in general are inadequate. Either an extensive redesign or a whole new approach is required.

6.6 END-USER ISSUES

The proposed end user is the Naval Surface Fire Support (NSFS) program office. Their design agent for the propelling charge was involved both in the development of the test criteria and in the evaluation of test results from the start of the program. This close coordination ensured that no major issue developed.

IHDIV is bringing the CLEVER technology to the Navy. There are procurements being formulated, and contracts are planned for the design and construction of both a nitramine precipitation plant and a continuous processing facility. The contracts for both facilities were awarded in FY 2000. The start-up and turn over to the government is scheduled to occur in 2004 for the nitramine precipitation plant and in 2002 for the continuous processing scale-up facility. Combined, these two facilities have a funding effort of over $20 million. The two facilities will transform IHDIV, NSWC propellant and explosive processing technology, reduce environmental impact, improve operational safety, and lead the transition of this technology to industry.

6.7 APPROACHES TO REGULATORY COMPLIANCE AND ACCEPTANCE

Operations at IHDIV, NSWC cannot proceed unless proper environmental permits have first been secured from the appropriate regulatory authorities. The introduction of a new process or changes/modifications to existing, permitted processes necessarily requires IHDIV to determine the need for potential environmental permit modifications. The CLEVER project conducted a comprehensive review of federal, state, and DoD-specific regulatory drivers impacting the implementation of the new production process. The review considered major environmental statutes and regulatory requirements addressing different environmental media (e.g., solid, liquid, and gaseous emissions) as well as safety and health implications. Because the environmental permitting process can be a lengthy experience, the facility's personnel have established a close working relationship with federal, state, and local authorities. This cooperative effort ensures the project will meet all environmental regulations and permit requirements. Permit modifications and applications are made through appropriate agencies of the Maryland Department of the Environment, Department of Natural Resources and Department of Housing and Community Development. These agencies are contacted and consulted as part of the process of modifying of or applying for a new permit. After review of the CLEVER process, it was determined to be covered under existing IHDIV, NSWC permits, so no new additional permits were required.

The CLEVER project has benefitted from a history of close cooperation with federal, state, and local regulators. Consultation and cooperation with environmental personnel and regulatory authorities will continue as CLEVER matures and will continue throughout the effective life cycle of the new production equipment. This will serve to minimize the potential down time attributable to regulatory issues and to ensure that the ability of IHDIV, NSWC to carry out its national defense mission is not unduly impacted.

The continuing review of potential issues associated with regulatory drivers further demonstrates the commitment of both IHDIV, NSWC and the CLEVER project to an environmental management approach that is comprehensive, open, and transparent to stakeholders.

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APPENDIX A

POINTS OF CONTACT

Point of Contact (Name)	Organization (Name & Address)	Phone/Fax/E-mail	Role in Project
Mr. Ashley Johnson	IHDIV, NSWC 101 Strauss Avenue Indian Head, Maryland 20640	301-744-6704 301-744-4187 johnsonag@ih.navy.mil	Surface Weapons and Ammunition Program Manager, Code PM2
Mr. Charles R. Painter	IHDIV, NSWC 101 Strauss Avenue Indian Head, Maryland 20640	301-744-6772 301-744-4187 paintercr@ih.navy.mil	Environmental and Chemicals Program Manager, PM4
Mr. Ulf Larsson	Nexplo Bofors AB SE-691 86 Karlskoga, Sweden	4658683148 ulf.g.larsson@nexplo.se	Project Manager, Bofors Precipitation Process Technology
Mrs. Constance M. Murphy	IHDIV, NSWC 101 Strauss Avenue Indian Head, Maryland 20640	301-744-6497 301-744-4843 murphycm@ih.navy.mil	Project Manager, Twin-Screw Extrusion Technology, Code 2330A
Mr. Michael R. Thornton	IHDIV, NSWC 101 Strauss Avenue Indian Head, Maryland 20640	301-744-1438 301-744-6223 thorntonmr@ih.navy.mil	Gun Systems Technology Branch Manager, Code 4210 (Design Agent)
Mr. Sven Lekander	Chiragene Inc. (formerly Bofors Explosives) 7 Powder Horn Drive Warren, New Jersey 07059	732-805-3664 sven.lekander@cambrex.com	Bofors Precipitation Process Technology POC
Ms. Valerie L. Plummer	IHDIV, NSWC 101 Strauss Avenue Indian Head, Maryland 20640	301-744-1926 301-744-4522 plummervl@ih.navy.mil	Project Engineer and ESTCP Principal Investigator
Mrs. Jennifer McKee	IHDIV, NSWC 101 Strauss Avenue Indian Head, Maryland 20640	301-744-2458 301-744-4843 mckeejj@ih.navy.mil	Gun Systems Project Engineer
Mr. William F. Newton	IHDIV, NSWC 101 Strauss Avenue Indian Head, Maryland 20640	301-744-1188 301-744-4697 newtonwf@ih.navy.mil	Twin-Screw Extrusion Process Engineer

ESTCP Program Office

901 North Stuart Street
Suite 303
Arlington, Virginia 22203

(703) 696-2117 (Phone)
(703) 696-2114 (Fax)

e-mail: estcp@estcp.org
www.estcp.org