General Atomics Electromagnetic Systems Group

13 December 2016

iSCWO: Hazardous Waste Destruction System for Energetics Destruction
BAE, Project Integration, Coterie, ARDEC, and RFAAP

Presented by: GA Electromagnetics Strategic Development
John Follin

General Atomics

LOCATION: San Diego, California

FOUNDED: 1955

STATUS: Privately held corporation

John Follin

Manager

Business Development

Demilitarization, Chemical Waste Destruction and Algae

GA is a recognized world leader in high-technology research, design, manufacturing, and production for industry and government in the U.S. and overseas

Demilitarization and Chemical Waste Destruction Products

Demilitarization

- Technology implementation for demilitarization of a variety of conventional munitions
- Activities with Military and Commercial entities

- Blue Grass Chemical-Agent Destruction Pilot Plant (BGCAPP) operations for the destruction of chemical warfare agents

Waste Destruction

- Large variety of applications of supercritical water oxidation (SCWO) for commercial uses
- Considerable growth for chemical waste destruction market for iSCWO






GA Safe Munitions Cryofracture Process

Munitions loaded into fixtures → Munitions cooled in LN_2 → Cryofracture Munitions → Thermally Treat Debris → Recycle Metal Scrap

Destroys munitions efficiently and thoroughly

Conventional Demil

McAlester Army Ammunition Plant (MCAAP)

- GA cryofracture system, with ongoing support of operations
- Recent upgrades to handle anti-personnel mines
- Long-term GA involvement for upgrades and operations

Crane Army Ammunition Activity (CAAA)

- GA transportable cryofracture system
- Planning resumed to install/operate system to treat expanded class of munitions (Rockeye, FASCAM, ICM)

Tooele Army Depot (TEAD)

- Performed successful cryofracture tests, followed by planning for cryo plant for cluster bomb units

Yuma Proving Ground (YPG)

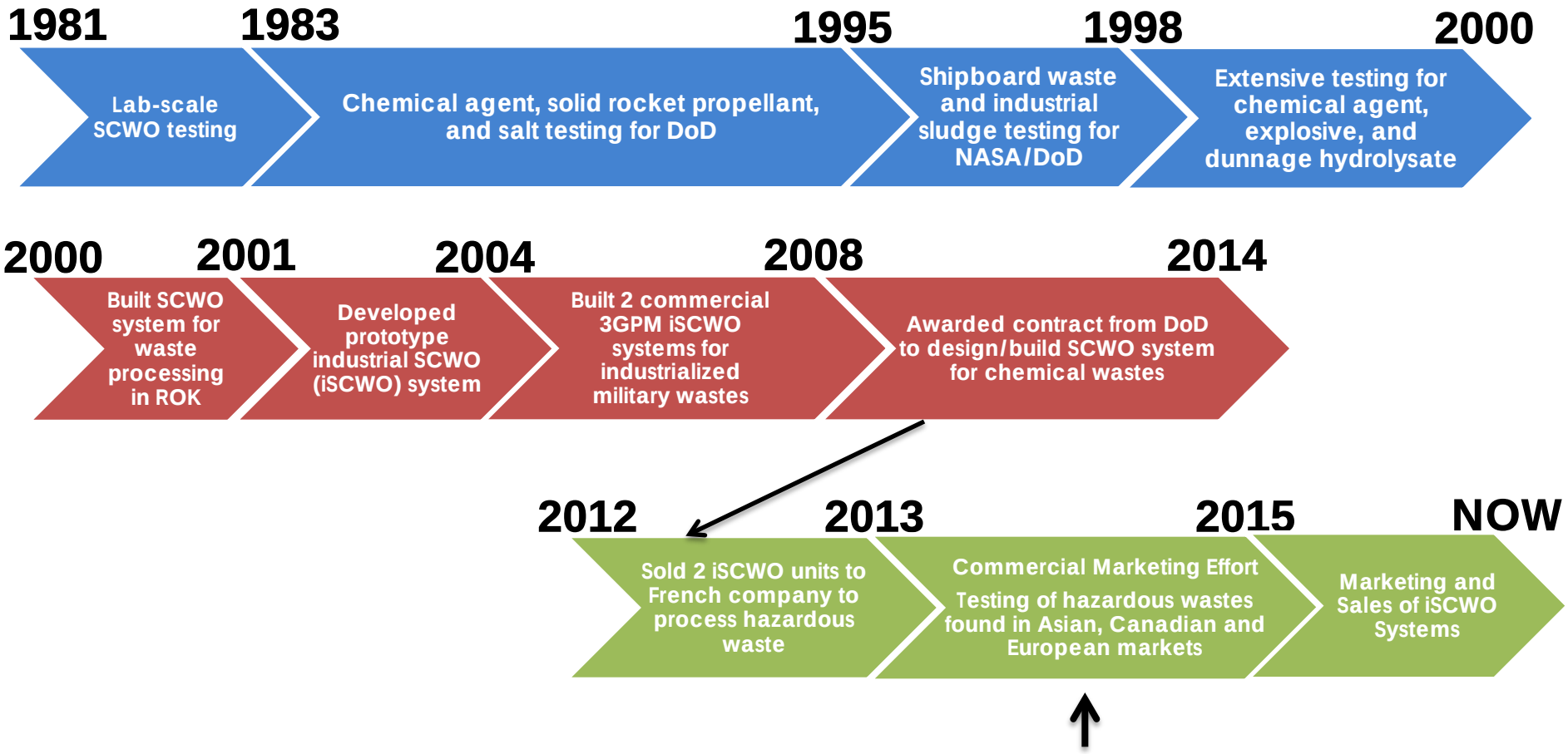
- Built cryofracture plant at YPG to demil ICMs

Why Supercritical Water Oxidation (SCWO) for GA?

Our past projects involve thermal treatment of energetic waste

- **We have built rotary kiln incinerators – they work (have high throughput) but have permitting, siting and logistics issues**
- **We have worked with different liquid chemical processing systems but they too have issues (waste water)**
- **Tested Molten Salt systems – process efficiency issues**
- **We have built and tested plasma arc systems but we encountered limited waste feed ability, short torch (electrode) life, material buildup in off-gas treatment, and high electrical costs**
- **In the late-1990's GA selected SCWO as a means for thermal treatment based on tests and customer requirements – this has worked well for GA**

GA SCWO Development Timeline



GA's SCWO Experience

- 22 years and $250M of SCWO development
- Built over 15 working SCWO systems
- Over 35,000 hours of steady state operations
- GA has processed a wide range of waste feeds including actual chemical agent, energetics, energetics hydrolysates and numerous industrial chemicals
- Expertise in salt transport to avoid salt buildup in reactor systems
- Experience in designing preprocessing systems including conveyors, grinders, and slurry systems

Use of SCWO/iSCWO in an Industrial Environment

iSCWO is excellent for the destruction of:

- Expired or obsolete pesticides, fertilizers, and fungicides
- Contaminated water (waste water cleanup)
- Expired or obsolete paints
- Petroleum and/or petrochemical waste streams
- Polychlorinated biphenyls (PCBs)
- Organic cleaning solutions
- Sewage sludge/animal waste products
- Fire retardant materials
- Energetic material (explosives or propellant)
- Materials not suitable for normal transportation or disposal

A Wide Range of Chemicals Successfully Treated with GA Technologies

Complex Feeds

- Activated carbon (spent)*
- Adhesives*
- Aqueous Cleaning Solution*
- AFFF
- Antifreeze*
- Aroclor 1242
- Aroclor 1254
- Aroclor 1260*
- Bacillus stearothermophilus (heat resistant spores)
- Brake fluid*
- Bran cereal
- Caprolactam wastewater
- Casein
- Chlorinated plastics (shredded)*
- Class 1.1 solid propellant*
- Class 1.3 AP-depleted solid propellant
- Coal
- Coal waste
- Corn flakes*
- Corn oil
- Corn starch
- Diesel fuel
- E. coli
- Endotoxin (pyrogen)
- Explosives/energetics/propellants (hydrolyzed RDX, TNT, Tetryl, NG, NC)*
- Fermentation byproducts*
- Fuel oil
- GB chemical agent (neat, hydrolyzed*)
- Gray water*
- Greases (mixed)*
- Human waste
- Hydraulic fluid*
- Industrial biosludge
- Ion exchange resins (styrene - divinyl benzene)
- Kerosene*
- Lube oil (molybdenum disulfide oil)*
- Malaria antigen
- Motor oil*
- Mustard chemical agent (neat, hydrolyzed*)
- Navy shore-based wastes*
- Olive oil
- Organic salts (complex mixtures)'
- Paint, paint sludges*
- Paper
- Paraffin oil
- Pesticide manufacturing wastewater
- Pharmaceutical waste*
- Photographic developer paste
- Photographic developer solutions*
- Polychlorotrifluoroethylene (PCTFE)*
- Pig manure
- Propellants (hydrolyzed)*
- Protein
- Pulp/paper mill sludge
- Sewage sludge (black water)*
- Soil contaminated with organics
- Soybean plants
- Sulfolobus acidocaldarius
- Transformer oil*
- Trimsol cutting oil*
- VX chemical agent (neat, hydrolyzed*)
- Waste oils (chlorinated and non-chlorinated)*
- Wheat straw*
- Wood fibers
- Yeast

Inorganic Substances

- Aluminum hydroxide*
- Aluminum metal
- Aluminum oxide sodium
- Ammonia*
- Ammonium chloride
- Ammonium nitrate*
- Ammonium nitrite*
- Ammonium perchlorate*
- Ammonium sulfate
- Ammonium sulfite*
- Boric acid
- Bromides
- Calcium carbonate
- Calcium chloride
- Calcium oxide
- Calcium phosphate
- Calcium sulfate
- Cerium chloride*
- Copper chloride
- Fluorides
- Hydrochloric acid*
- Hydrofluoric acid
- Iron chloride
- Iron oxide*
- Lead chloride*
- Lead sulfate*
- Lithium hydroxide
- Lithium sulfate
- Magnesium nitrate
- Magnesium oxide
- Magnesium phosphate
- Magnesium sulfate
- Mercuric chloride
- Molybdenum disulfide lube oil*
- Nitric acid*
- Phosphoric acid
- Potassium bicarbonate
- Potassium carbonate
- Potassium chloride
- Potassium hydroxide
- Potassium sulfate
- Silica
- Sodium bicarbonate*
- Sodium carbonate
- Sodium chloride*
- Sodium fluoride*
- Sodium hydroxide*
- Sodium nitrate
- Sodium nitrite
- Sodium phosphate*
- Sodium sulfate*
- Sodium sulfite·
- Sulfur, elemental
- Sulfuric acid*
- Titanium dioxide
- Zinc chloride*
- Zinc sulfate*

Organic Chemicals

- Acetic Acid
- Acetone
- Acetylsalicylic acid(aspirin)
- Adumbran
- 4[(2-Amino-3, 5-dibromophenyl)-methylamino]cyclohexanol
- Ammonium acetate*
- Ammonium formate*
- Ammonium oxalate*
- Benzene
- Biphenyl
- Butanol*
- Calcium acetate*
- Carbon tetrachloride*
- Carboxylic acids
- Carboxymethyl cellulose
- Cellulose
- Cerium Acetate*
- Chlorinated dibenzo-p-dioxins
- 6-chloro-2,3,4,5-tetrahydro-3-methyl-1H-3-benzazepine hydrochloride
- Chlorobenzene*
- Chloroform*
- 2-Chlororphenol*
- o-Chlorotoluene*
- Cobalt acetate
- m-Cresol*
- Cyanide*
- Cyclohexane
- DDT
- Decachlorobiphenyl
- Dextrose
- Dibenzofurans
- 3,5-dibromo-N0cyclohexyl-N-methyltoluene-,2-diamine
- Dibutyl phosphate
- Dichloroacetic acid
- Dichloroanisole
- Dichlorobenzene
- 4,4-Dichlorobiphenyl
- Dichloroethylene
- Dichlorophenol
- Diethanolamine*
- Dimethylformamide*
- Dimethyl methyl phosphonate (DMMP)*
- Dimethyl sulfoxide*
- 4,6-denitro-o-cresol
- 2,4-Dinitrophenol
- Dinitrotoluene
- Dipyridamole
- Diisopropyl ethanolamine
- Diisopropyl ethylamine
- Ethanol
- Ethyl acetate*
- Ethylene chlorohydrin
- Ethylenediamine tetraacetic acid
- Ethylene glycol
- Fluorescein*
- Freon 22
- Glycerol
- Hexachlorobenzene
- Hexachlorocyclohexane
- Hexachlorocyclopentadiene
- Iron acetate*
- Isooctane
- Isopropanol*
- Lead acetate*
- Mercaptans
- Mercaptoethanol
- Methanol*
- Methyl acetate*
- Methyl cellosolve
- Methylene chloride*
- Methyl ethyl ketone
- Methylphosphonic acid (MPA)
- Monoethanolamine*
- Nitrobenzene*
- 2-nitrophenol
- 4-nitrophenol
- Nitrotoluene
- Octachlorostyrene
- Octadecanoic acid magnesium salt
- Paracetamol
- Pentachlorobenzene
- Pentachlorobenzonitrile
- Pentachlorophenol*
- Pentachloropyridine
- Phenol
- Polychlorinated biphenyls (PCB*)
- Polychlorotrifluoroethylene*
- Sodium acetate
- Sodium formate
- Sodium hexanoate
- Sodium isethionate*
- Sodium propionate
- Sucrose
- Surfactant
- Tetrachlorobenzene
- Tetrachloroethylene*
- Tetrapropylene H
- Thiodiglycol*
- Toluene
- Tributyl phosphate
- Trlchlorobenzenes
- 1,1,1-Trichloroethane*
- 1,1,2-Trichloroethane*
- Trichloroethylene
- Trichlorophenol
- Trifluoroacetic acid
- 1,3,7-Trymethylxanthine
- Unsymmetrical dimethyl hydrazine
- Urea
- o-Xylene*
- Zinc acetate*

SCWO Influents and Effluents Examples


Glycol (maximum antioxidant)


Gray water


Motor oil (high heat value with zinc)


MoS_2 lube oil/kerosene (maximum sulfur)


Paint (maximum solids)


Black water

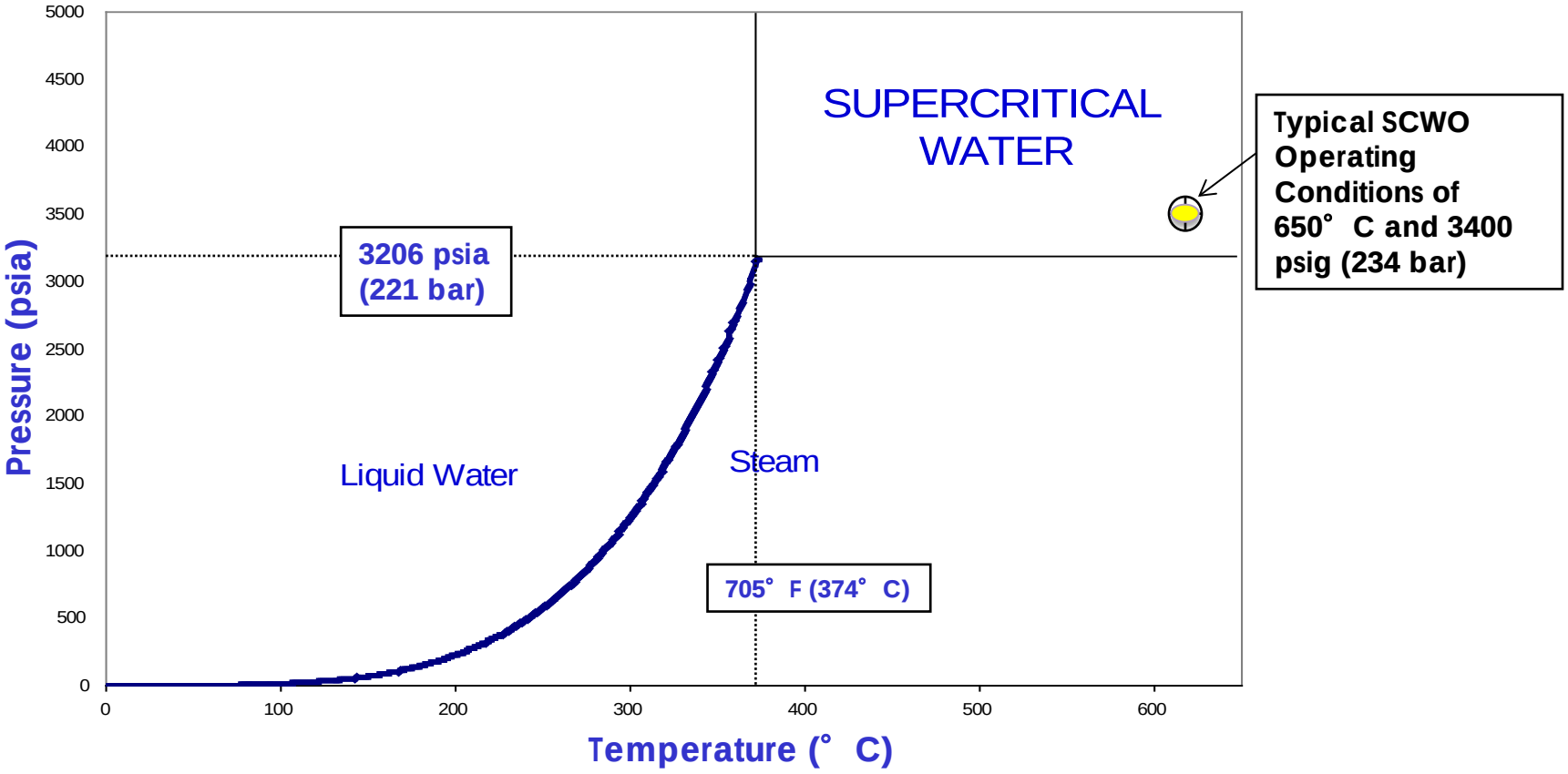

Hydraulic fluid (high heat value with maximum phosphorus)


Organic solvent (high in dissolved iron and copper)

Complete destruction of organic material

SCWO Technology

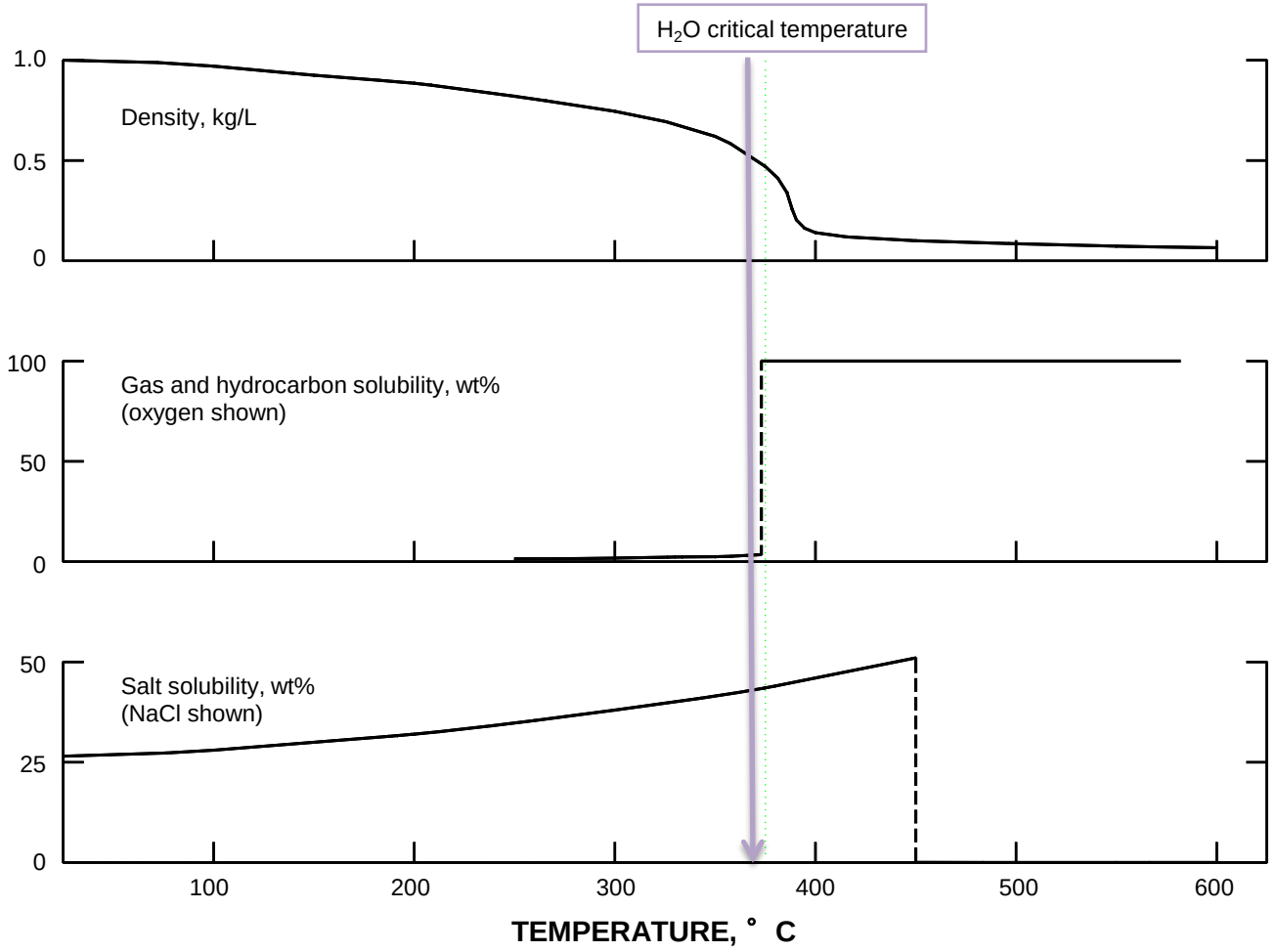
What is Supercritical Water?



Supercritical water is water that is heated and pressurized above its thermodynamic critical point of 374° C and 221 bar.

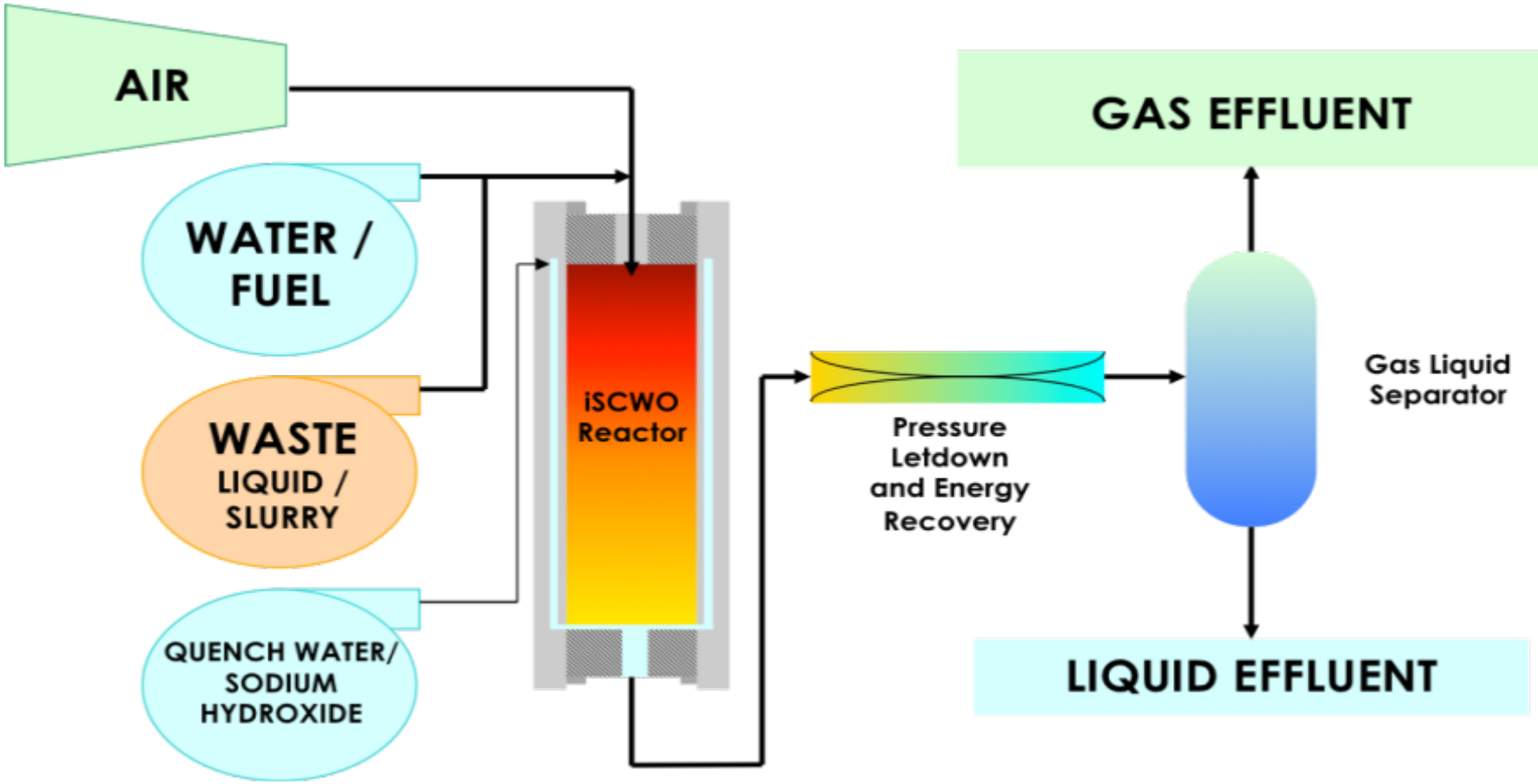
We operate at 650° C and 234 Bar to ensure complete oxidation of wastes.

SCW Properties

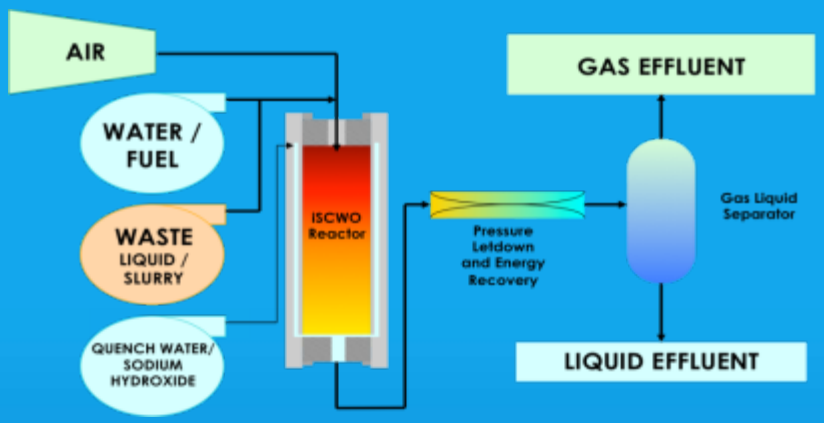


PRESSURE = 250 bar (3626 psig)

iSCWO Process Flow



iSCWO: Technical & Cost Advantages



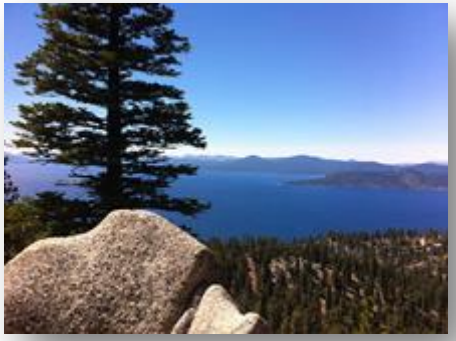
- Perfect for onsite waste destruction
- Cost competitive with incineration or any other oxidation process at site
- No airborne particulates
- No afterburner or complex secondary processing equipment
- Clean water by-product required little of now post-treatment prior to discharge to POTW
- Air supply for oxidant instead of LOX
- Simple design – easily maintenable
- Waste stream testing in San Diego

Rapid, complete organic destruction with no pollution abatement system

iSCWO Offers Significant Advantages

- **Efficient waste destruction at supercritical conditions due to high solubility of organics and oxygen plus excellent reaction kinetics**
- **iSCWO process uses chemical energy released from oxidation of organics in feed streams maintain internal reactor temperature of 650° C – self sustaining**
- **Liquid waste feed can be very dilute to highly concentrated wastes**
- ***NO Pollution Abatement System (PAS) required***
- **Effluents contain non-detect levels of nitrogen oxide (NO_X), sulfur oxide (SO_X), and total organic carbon (TOC) plus no airborne particulates**
- **Uses high pressure air as oxidant source versus liquid oxygen**
- **Can achieve Destruction Removal Efficiency (DRE) for TOC >99.99% (non-detect)**

iSCWO Release Streams Meet Environmental Requirements



Waste Feed	Gas Release	Liquid Release
iSCWO Waste Feed	O_2 CO_2 Water vapor Organic free	Organic-free water Some salts (depending on chemical feed) Metallic oxides particles (depending on chemical feed)

All Liquid Releases Designed for Discharge Directly to a Public Owned Treatment Works (POTW)

Perfect for Onsite Waste Processing

- System is very cost effective for onsite waste destruction
- As limits are placed on incineration and hazardous waste transportability issues, onsite waste destruction is attractive
- Processing equipment has a small footprint
  ~25’ x 8’ x 15’ (L x W x H)
- Multiple systems can be added in parallel to increase capacity (x 3GPM)
- Solid materials can be ground and slurried for iSCWO processing
- No afterburner or complex secondary processing equipment
- Simple control system means minimal manpower required for treatment of hazardous materials

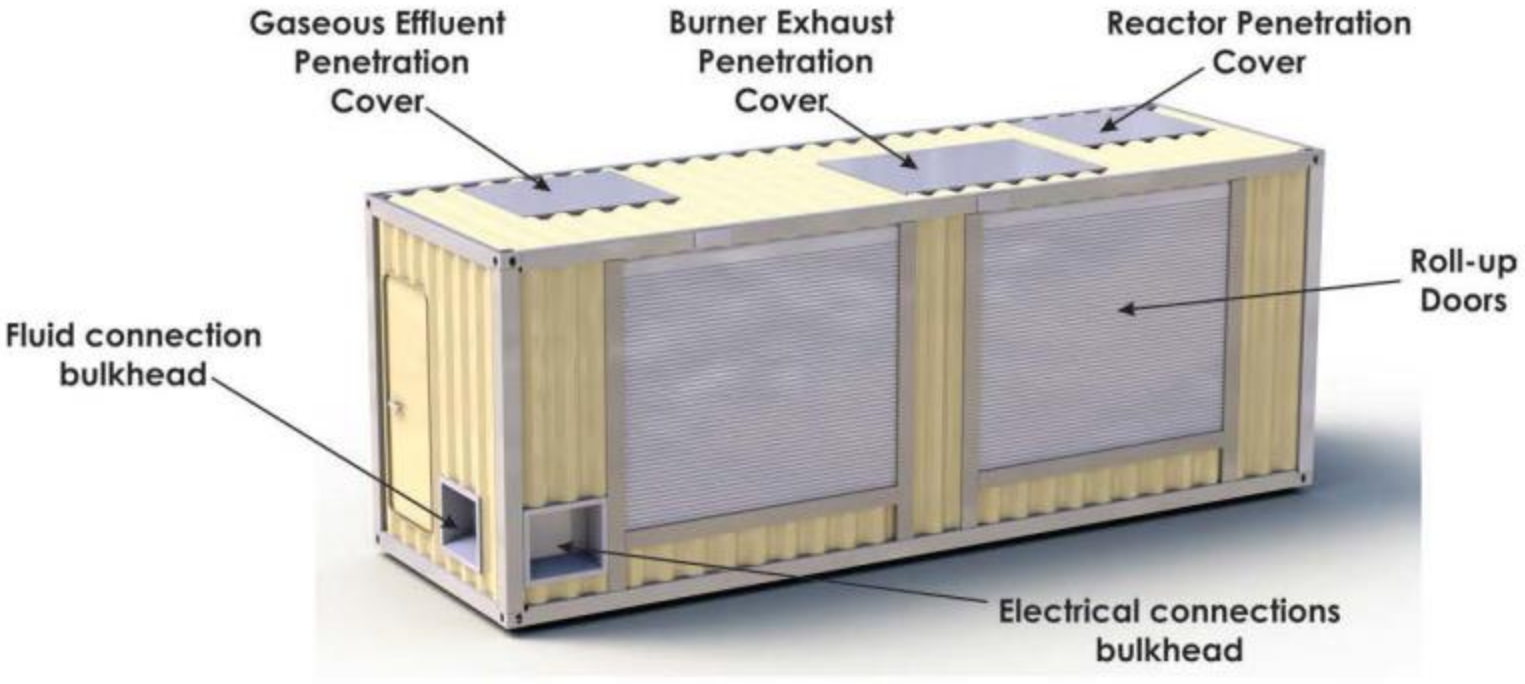
What we offer - Modular iSCWO Systems

3 GPM iSCWO skid

3 GPM transportable iSCWO system

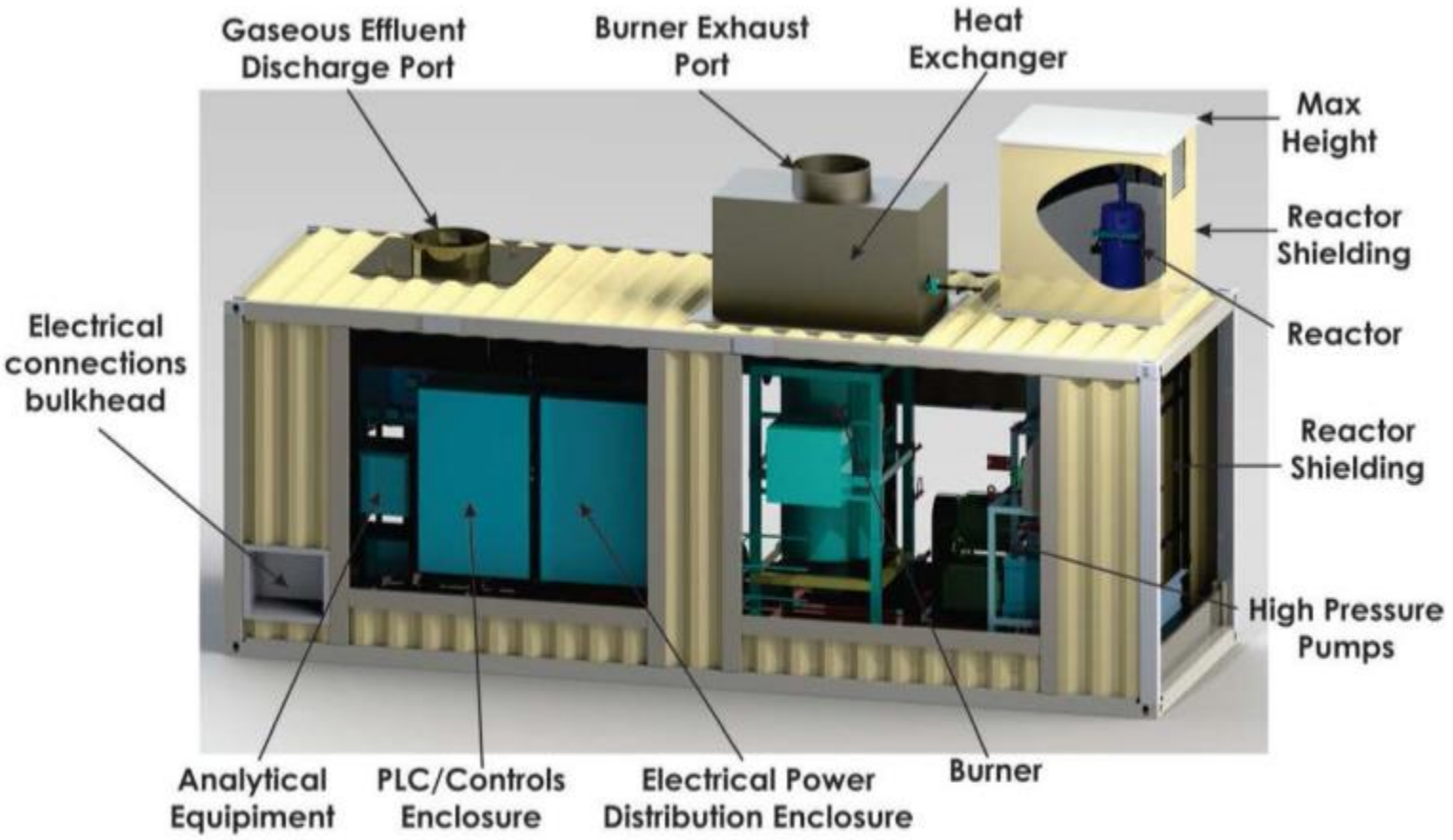
Modular design allows for rapid setup and start of process operations

3 GPM Shipping Configuration



3-gpm iSCWO Shipping Configuration
25 feet long by 8 feet wide by 9.5 feet tall
Approximate weight = 20,800 pounds

3 GPM iSCWO Assembled Configuration



3-gpm iSCWO Assembled Configuration
Maximum Height = 14.5 feet

Fixed Facility iSCWO Systems

iSCWO System with Tanks

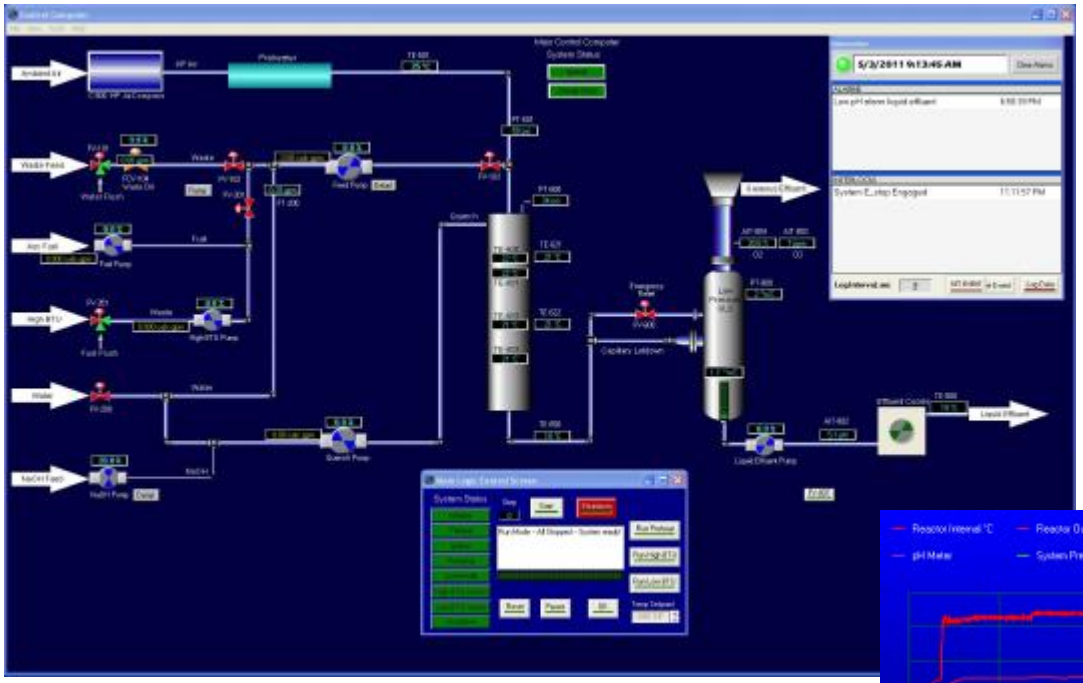
Complete Facility with control room, service rooms, offices, and waste-in receiving and inspection areas

iSCWO systems can be part of new or existing processes

iSCWO Process Control

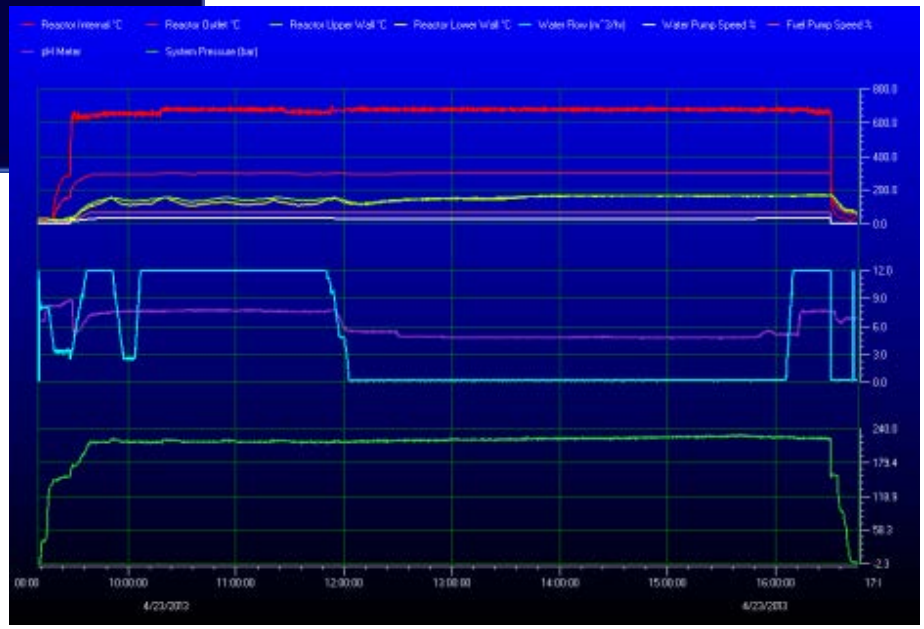
- iSCWO control system is very intuitive – operates like a video game
- Easy-to-read displays (system charts and graphic diagram)
- Basic modes of operation: Maintenance and Operation
- Maintenance mode: Interlocks and alarms are disabled and everything is controlled manually
- Operation mode: All interlocks and alarms are enabled. Single push button sequential operation including preheat, ignition, idle, waste processing and Shutdown
- In English or Metric Units
- Customized user language

iSCWO Control Screens



← PFD based control screen

Real time data plots →



Data stored for environmental review

iSCWO System Design Specifications

iSCWO equipment design meets American and European code Requirements:

- **American requirements**
  - –American Society of Mechanical Engineers (ASME)
  - –US National Electric Code
  - –American Petroleum Institute (API)

- **European requirements**
  - –European Pressure Equipment Directive (PED)
  - –European Machinery Directive 2006/42/CE
  - –European Voltage Directive 2006/95/CE
  - –Wiring Directive IEC 60204-1

- **QA/QC**
  - –All project phases executed per ISO-9001 requirements

GA iSCWO Typical Scope of Supply

- The typical iSCWO system includes:
  - Skid mounted system (pumps, reactor, gas/ liquid separator, controls)
  - Gas and liquid effluent monitoring equipment
  - American, Asian and European electrical and mechanical standards (including pressure)
  - Acceptance testing at GA
  - Shipping to nearby customer port
  - Installation, start-up and checkout supervision
  - Training and documentation (e.g., O&M manuals and design documents)

Customer acceptance tests at GA

27

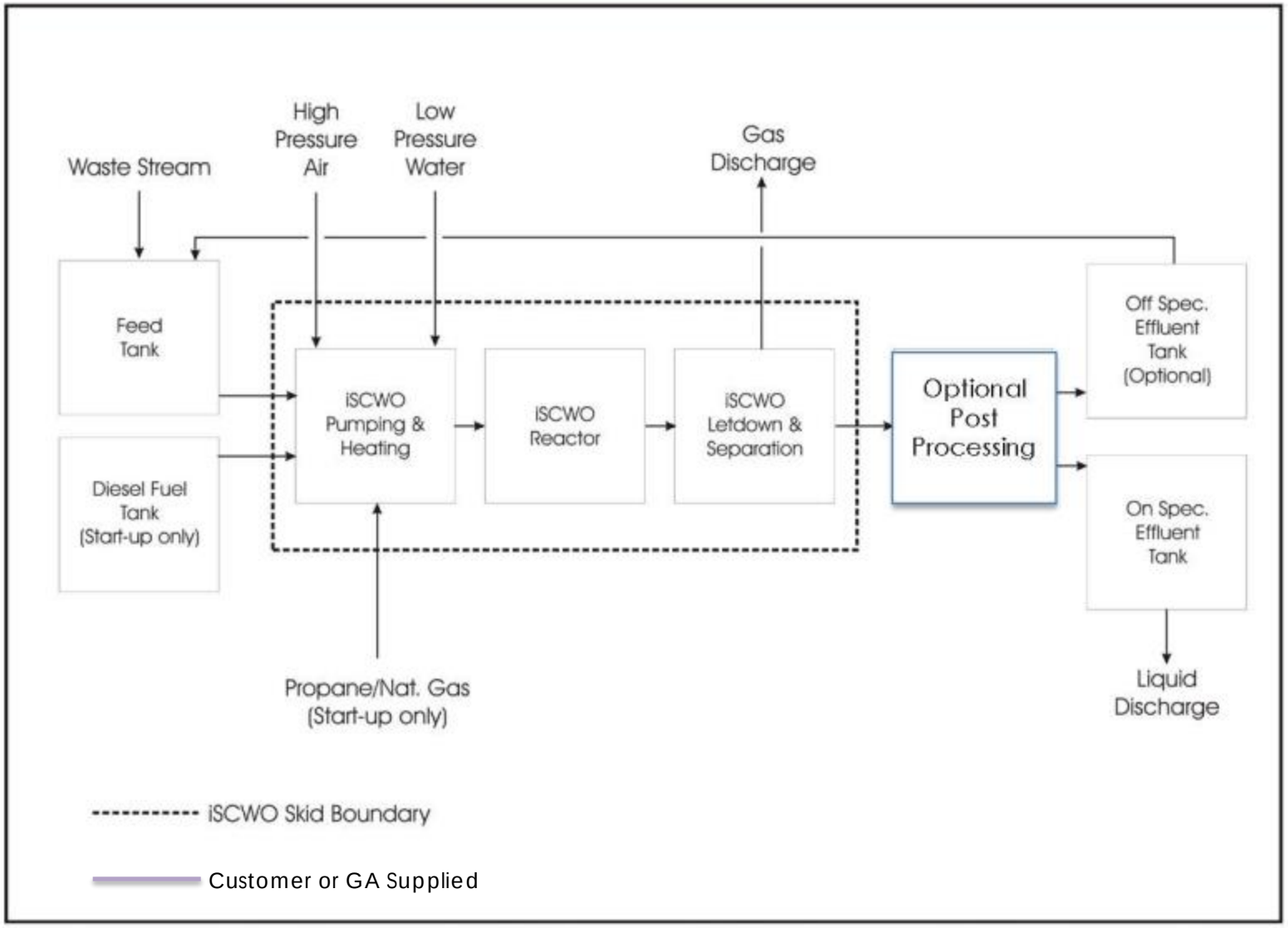
GA iSCWO Customer Scope of Supply

- **Typical customer scope of supply for GA iSCWO includes:**
  - **Installation site**
    - Requirements determined on a case-by-case basis
    - Customization of iSCWO equipment is possible to meet site requirements
  - **Utilities**
    - Electrical, water, ventilation, telecommunications, fire suppression (if required), propane/natural gas and instrument air
  - **Feed mixing and delivery system**
    - 3 gpm at ~30 psig
    - Tank mixing and heating (if required)
    - High pressure air compressor package
  - **Fuel storage tank and delivery system**
    - 0.25 gpm at ~50 psig
  - **Effluent holding tanks and pump-off system**
    - Including filtration and ion exchange if required to meet discharge requirements
  - **All required permits**

Preprocessing Steps for iSCWO

- Previous iSCWO systems have required the development of integrated components to prepare the waste for iSCWO destruction
- Rarely is the waste feed a “deliver and pump in” process
- Experience in energetics (explosives and propellant) along with other chemical waste feeds requiring preprocessing steps
- Some steps include pre-concentrating, blending, filtering and other waste pretreatment technologies
- GA has extensive experience in selecting the proper pre and post treatment components required for the specific waste to be processed by iSCWO

Typical iSCWO Boundary Limits



GA History at Camp Minden

- **Shipped a 3gpm iSCWO system with compressor to Camp Minden for testing**
- **Performed limited testing at Camp Minden**
  - **Rocket AP**
  - **Yellow D**
  - **HC Smokes**
  - **Cleaning Solutions**

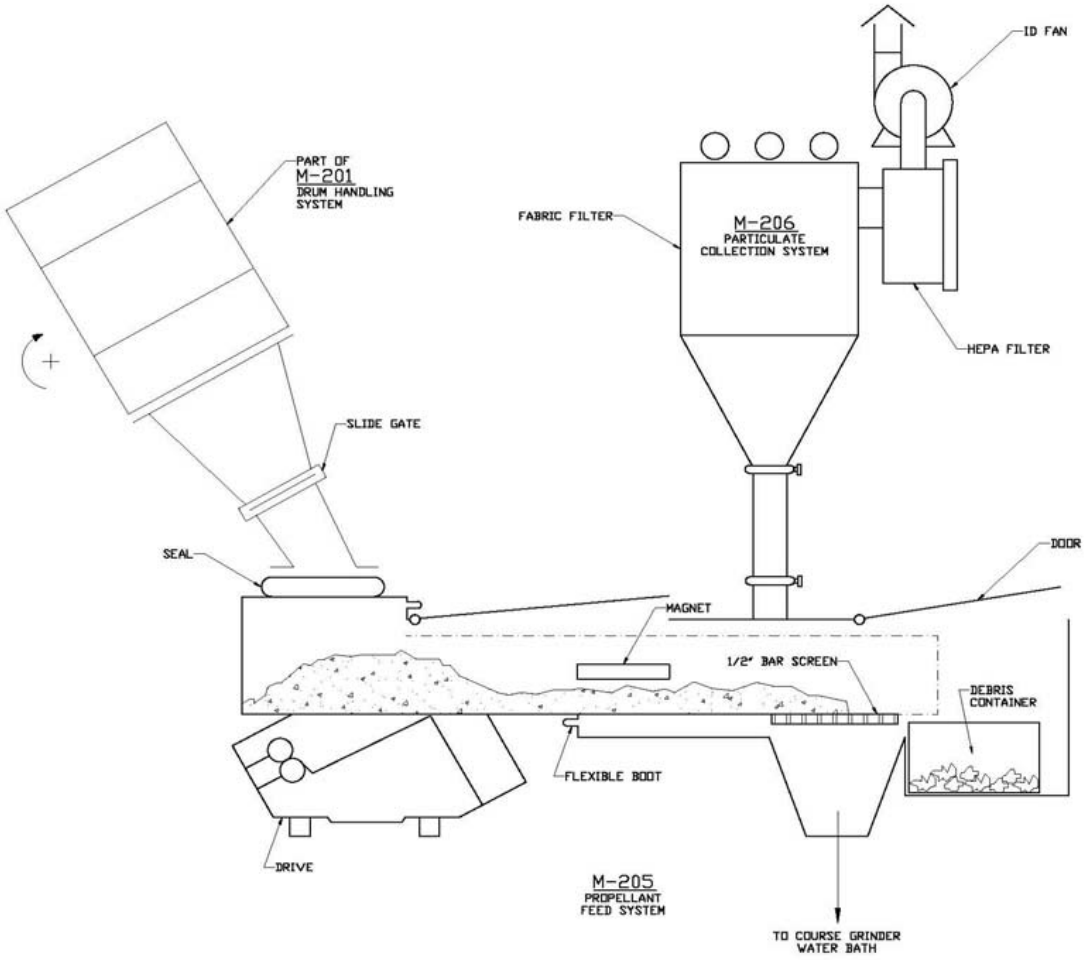
- **Began Assembling 10gpm unit at Camp Minden**
- **All worked stopped because of Explo System Bankruptcy**
- **US Army requested 10gpm unit to be shipped to MCAAP**
- **GA cleaned/removed any liquids at Site**
- **3gpm unit still at Camp Minden**

Camp Minden 3gpm iSCWO System

3 GPM iSCWO Skid

3 GPM iSCWO Tanks

Camp Minden 3gpm iSCWO System – Slurry Feed



Customer Interaction

Some of GA iSCWO Activities

Excellent Application of iSCWO for On-Site Waste Destruction

Some examples of iSCWO Applications

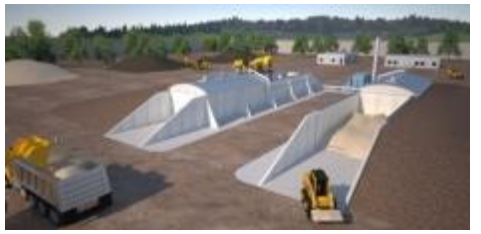
Ground water cleanup

Sewage Concentrate destruction

Pesticide destruction

Petroleum Waste Destruction

Illegal Chemical Destruction



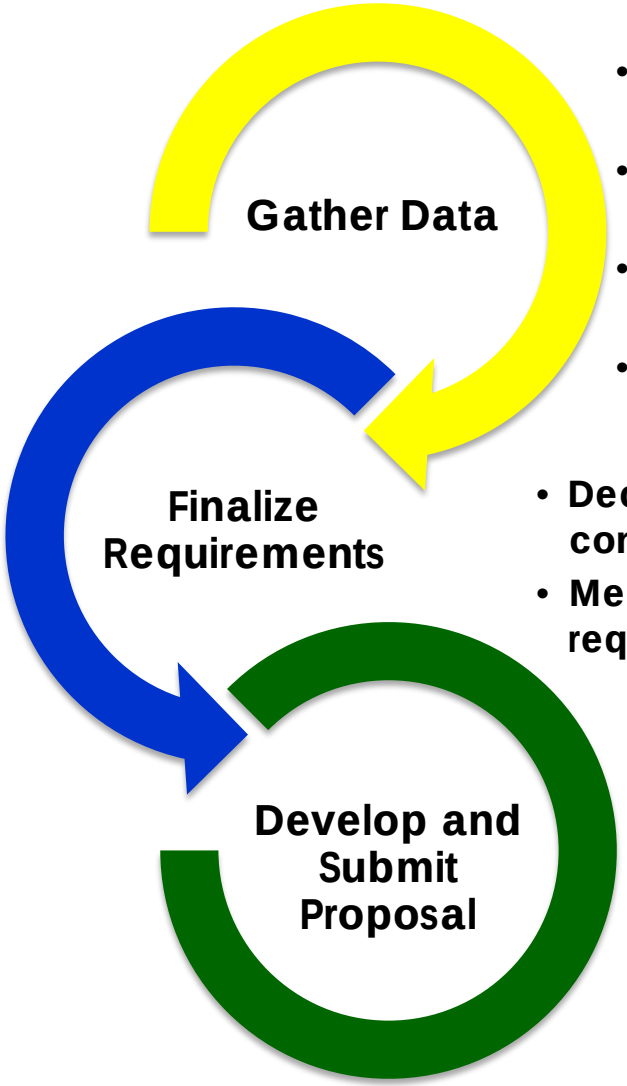
Clean Contaminated Soils

River water cleanup

Chemical Process Waste Treatment

Chemical Waste Destruction

Customer Engagement Process



- Determine wastes' chemical composition
- Define waste pre-treatment requirements
- Define interface, siting and schedule requirements
- Define throughput and effluent discharge requirements

- Decide if testing at GA is required; conduct testing if necessary
- Meet with customers to finalize requirements for RFP

- Scope of equipment supply
- Scope of work (installation, checkout/startup, support operations)
- Spare parts
- Schedule and deliverables
- After sales support

GA iSCWO Demonstration System

iSCWO System used for different chemical waste treatment tests

Dedicated iSCWO Test Facility

System arrangement allows for easy tests with data analysis

Conclusions

- Simple to operate, automated and easy maintenance
- iSCWO is an excellent waste destruction process suitable for ***onsite*** treatment of organic wastes at affordable cost
- iSCWO is fully capable of destroying a wide range of pumpable hazardous waste to strict environmental standards
- Mobility for multi-site waste destruction
- iSCWO systems use air rather than liquid oxygen which makes the processing site easier to permit and eliminates a number safety issues related to LOX systems.
- No pollution abatement system necessary to meet environmental regulations
- GA has 22 years experience with SCWO systems
- GA provides testing capability and effluent analysis for customers – know before you buy

Contact Information

Thank you very much for your time!

John Follin
Business Development Manager
Demilitarization, Chemical Waste Destruction and Algae Systems
General Atomics Electromagnetic Systems Group
1 858 964 6805 (office)
John.Follin@ga.com