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Questions

Please see us at our booth after the presentation
Treating solids, liquids & gases with plasma
Oil Shale Processing

Water Treatment

&

CO₂ Sequestration

With Plasma

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Presented to

27th Oil Shale Symposium

October 16, 2007

By

Kip Wintenburg
Cliff McClain
Todd Foret
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Introduction

By: Kip Wintenburg

Water and greenhouse gas emissions are two critical and emerging issues in the development of shale oil from the Green River Formation of Colorado, Utah, and Wyoming. According to estimates by Los Alamos National Lab and Earth and Environmental Sciences, 3.5% to 8% of the 5.3 million acre-ft/yr of water allocated to these Upper Colorado River States may be utilized for oil shale production.\(^1\) A recent issue for the development of oil shale is concern about the quantity of CO\(_2\) co-produced as oil shale kerogen is pyrolyzed. A recent model confirms that power plant emissions are likely the dominant source of CO\(_2\) and that uncertainty about the heat required to produce a barrel of shale oil remains a critical uncertainty.\(^2\)

\(^{1}\) WILSON, Cathy J. and FOSTER, Jean M., Earth and Environmental Sciences, Los Alamos National Lab, EES-10, MS J495, Los Alamos, NM 87544, cjw@lanl.gov

\(^{2}\) Jeremy Boak, Colorado School of Mines, “Estimate of CO2 Production for In-Situ Production of Shale Oil from the Green River Formation in Western Colorado.”
# Potential Plasma Applications within Green River Basin

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## FPL Proprietary Plasma Systems & Torches

<table>
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<tr>
<th>System</th>
<th>Description</th>
<th>Application</th>
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| **PlasmaWhirl™** | • High Temperature Plasma  
• Refractory Lined  
• Modules installed with Rotary Kiln, Cyclone Separator, etc.  
• Gasification & Separation in one step  
• Multiple Torches  
• Up to 15 MW/torch  
• 90 MW module  
• Modules Stacked | **Solids**  
**Liquids**  
**ArcWhirl™**  
**Disinfection**  
**Melter**  
**Hi-TEMPER™** |
| **PlasmaWhirl™** | • Air Core in Hydrocyclone replaced with plasma core  
• Multiple Units installed on inlet and outlet headers  
• Gasification & Combustion in one step  
• Single Torch  
• Up to 100kw/torch  
• Very Lean Combustor | **Liquids**  
**ArcWhirl™**  
**Disinfection**  
**Melter**  
**Hi-TEMPER™** |
| **ArcWhirl™**    | • Carbon Arc  
• Multiple Units installed on inlet and outlet headers  
• Heavy Oil Upgrading  
• Syngas Production  
• Biomass Gasification | **Disinfection**  
**Melter**  
**Hi-TEMPER™** |
| **ArcWhirl™**    | • Same as ArcWhirl  
• Single large unit with reflector for increasing irradiation time  
• Ultra High Volume Disinfection  
• IR Drying | **Disinfection**  
**Melter**  
**Hi-TEMPER™** |
| **ArcWhirl™**    | • Carbon Arc  
• Water Cooled Reactor with no refractory lining  
• Vitrification + Fast Quench in one step  
• Biomass Diesel | **Melter**  
**Hi-TEMPER™** |
| **Hi-TEMPER™**   | • Plasma Electrolysis  
• Liquids with high conductivity  
• Hydrogen Generation  
• Caustic Regeneration  
• Electrolysis Cell  
• Up to 15 MW/Cell |
Mass transfer is the phrase commonly used in engineering for physical processes that involve molecular and convective transport of atoms and molecules within physical systems. Mass transfer includes both fluid flow and separation unit operations.

http://en.wikipedia.org/wiki/Mass_transfer

Examples:
Mining – Air Sparged Hydrocyclones, Froth Flotation
Drilling – Hydrocyclones, Shale Shaker
Production – Induced Gas Flotation Cell
Refinery – Distillation Columns, Strippers, Reactors, etc.
Water Treatment – Dissolved Air Flotation
Metals Industry – Arc Melting, Electrolysis, Resistive Heating
Pulp & Paper – Lime Kiln, Black Liquor Evaporation
Hydrocyclones are commonly used in mining, drilling, pulp & paper
Hydrocyclones – Vortex or “WHIRL” Flow
Conduction – thru wall of pipe or medium
Convection – via air, steam or fluid
Radiation (Wave Energy)
- EMR - Gamma, X-Ray, UV, IR, Microwaves, RF,
- Corpuscular – electrons, cations, anions
- Sonic

"wave energy" includes radiation as well as wave energy transmitted by various mediums and embraces electromagnetic wave energy or radiation, sonic and supersonic waves, neutron, proton, deuteron, and other types of corpuscular radiation.

http://www.uspto.gov/web/patents/classification/uspc204/defs204.htm
Heat Transfer 101 - Conduction

Through wall of pipe

Heating Inconel 625
Heat Transfer 101 - Convection

From Plasma to Water

From Plasma to Air
Heat Transfer 101 - Radiation

IR through Glass

IR from plasma to hand

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Plasma 101

By: Kip Wintenburg

- 4th state of matter
- Electrically conducting
- Ionized gas
- Extreme temperatures
Plasma 101 – 99% of universe exists in the plasma state
Plasma 101 – Why Plasma?

By: Cliff McClain & Kip Wintenburg

- Plasma is **four times more efficient** for heating at High Temperatures (Electrical Power Research Institute - EPRI)
- Gasification & Water Treatment in one step
- Economics
  - Potential net energy producer
  - Low capital cost
- Physical Characteristics
  - Ready technology
  - Off the shelf modular components
  - Very Compact – transportable
Plasma 101 – EPRI Graph Plasma vs Fossil Fuels

Graph reproduced with permission from EPRI via Ametek HDR Sr. Engineer, George Sites

http://www.hdrgroup.com/app/1001.asp

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Plasma heat contains more available energy for work than fossil fuel at high temperatures. Although the electricity used for making plasma may cost two to three times as much as fossil fuels, four times as much available energy is contained in plasma heat than is possible with fossil fuels.

Fossil fuel flames have a practical limit of 3600° F (2000° C). At 2900° F (1600° C), only 20% of the energy in a fossil fuel flame is available for melting metal, but more than 80% of the energy in the plasma heated air is available.¹

¹Reproduced with permission from Ametek HDR Sr. Engineer, George Sites
Although the Plasma Torch has been around for many years, the applications are just becoming known. Now with the advancements in power electronics and control methods the applications are more wide spread than ever due to the increased controllability of the arc.

The small size, minimal installation costs and the ability to use different gasses are all benefits of the Plasma Torch. However, the greatest advantage is the ability to provide and maintain accurate temperature control.\(^1\)

\(^1\)Reproduced with permission from Ametek HDR Sr. Engineer, George Sites

Inertial and Magnetic

Inertial Confinement

Angular Momentum or high velocity gases or used to Pinch or Squeeze the plasma and contain it within the center

Typical everyday applications:

- Plasma Cutting, Gouging & Spraying

- ESAB PT 19 Torch

- Transferred Arc Torch
Plasma Confinement – Transferred Arc Mode

- **Hot Water**
- **Cooling Water**
- **Plasma Gas**: Argon, N₂, O₂, Ar+H₂, He, etc.
- **Shield Gas**: Air, N₂, O₂, Ar, H₂, He, etc.
- **Arc**
- **Anode Nozzle**
- **Cathode**
- **Plasma Plume**
- **Arc Transferred to Workpiece**
- **Electrically Conductive Workpiece**

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Plasma Confinement – NON - Transferred Arc Mode

- Hot Water
- Plasma Gas
- Air, N₂, O₂, Ar, H₂, He, etc.
- Cathode
- Arc
- Plasma Plume
- Anode
- Cooling Water

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Plasma Confinement – NON - Transferred Arc Mode

Water Cooled Electrodes: Heat loss to water = Equivalent of 30% of Torch Power

NOTE: “The system is a closed-loop configuration with a pump and heat exchanger. The heat exchanger should have a maximum capability to dissipate the equivalent of 30% of the torch power with heat removed by the plant recirculating water system.”

See: http://www.westinghouse-plasma.com/westinghouse/ie/plasmatechnology/pt_main_is.htm

The core of the arc is found to be close to LTE, with a central plasma temperature of 6,200 deg K in the non-transferred mode, and approx. 15,000 deg K in the transferred mode.

See: http://stinet.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA360841
Plasma Confinement – ArcWhirl™ with Water

Any Waste with organics

Cathode

Arc

Water

Anode

Plasma Plume (Supersonic)

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10/9/2007
Inertial and Magnetic

Magnetic Confinement

Returning back to the fact that a plasma is electrically conductive, it also can be contained with magnetism

Typical everyday applications:

NONE

Hopefully one day - Fusion
If 2 of natures’ most powerful forces could be coupled, what would be the possibilities?

Cyclone + Plasma
Plasma Cyclone – Mine’s Closed-Top Cyclone Reactor

U.S. Patent No. 5,228,901

http://www.mines.edu/academic/met/plasma/facilities.htm
Reproduced with permission from Dr. Patrick R. Taylor
Plasma Cyclone – FPL PlasmaWhirl™ for Liquids

Plasma Torch

Cathode (-)

Anode (+)

Water

hydrocyclone

ESAB 150

350 VDC 150 amps 130 amps Continuous Duty
Plasma Cyclone – FPL PlasmaWhirl™ for Solids

Plasma Torches
Cathodes (-)
Anodes (+)

hydrocyclone

ESAB 150
350 VDC 150 amps
130 amps Continuous Duty

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Plasma Cyclone – FPL ArcWhirl™ for Solids or Liquids

- Cathode (-) - Water - hydrocyclone
- Anode (+)

HDR Ametek
250 VDC 400 amps
Continuous Duty

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Replacing the air/gas core in a hydrocyclone with a plasma core.

Arc Light™
World’s most powerful
Advanced Oxidation System
Plasma Mass Transfer
PlasmaWhirl™ Reactor Technology Approach

- Containment of the Plasma Core without MELT DOWN of Reactor
  - Utilize Common Refractory as Plasma Facing Material
  - Achieve Core Temperature greater than 5000°F

- Feed solids without any pretreatment
  - Utilize Angular Momentum of Plasma Jet for:
    - Grinding
    - Separating

- Separation – Mass Transfer

- Ultra-low CAPEX, Compact, Mobile and Modular
ArcWhirl™ Technology Approach

- Containment of the Plasma Core without Refractory Lining
  - Create and Sustain WHIRLPool
  - NO Refractory Lining

- Multiple Feed Inlets with Preheating
  - Solids
  - Liquids
  - Gases

- Separation – Mass Transfer

- Various Modes of Operation with same System
What happens with ArcWhirl when flooded with high conductivity solution
- Electrolysis
- Plasma

Are there any low flow weak solutions that electrolyte can be added to?
- Yes

What environmental friendly electrolytes are commonly used in industry?
5 reasons why Electrical Technologies are right for Oil Shale Development

1. CaCO₃ (Lime)
2. NaHCO₃ (Baking Soda or Caustic)
3. DRY – no free moisture; can be comminuted

Technology Approach & Coming Full Circle with a Whirl

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Adopting Foundry Technologies – Sand Exiting Reclaimer

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ArcWhirl Produced Water Treatment System

16” ArcWhirl™ - 30,000 BBL/day
ArcWhirl Produced Water Treatment System - Inlet
PlasmaWhirl™ Dual Torches with Power Supplies
120 KW ArcWhirl™ Melter
HiTemper™ for Downhole Applications
4” Casting - CF8M (316-L) Hydrocyclone Volute
Multiple Torch PlasmaWhirl™ Modules

70 KW 2 torch PlasmaWhirl™ Research Trailer/Skid
1 Ton/hour Oil Shale

720 KW 6 torch PlasmaWhirl™ Trial Unit
10 tons/hour Oil Shale

7.2 MW 6 torch PlasmaWhirl™ Module
100 tons/hour

90 MW 6 torch PlasmaWhirl™ Module
30,000 tons/day
Dual Torches

Rating: 70 KW
Feedrate: ½ lb/second
Residence Time: 1 sec.
Temperature: + 3,500°F

Temp Rise for Foundry Sand + Drill Cuttings:
75°F → 1,500°F in 1 second
Energy for treating Drill Cuttings\(^1\) or Foundry Sand\(^2\)

68 KW/ton

232,084 BTUs/ton

\(^1\)Removal of Oil based drilling fluids for ROC (retention on cuttings) below detectable limits.

\(^2\)Burn-off of carbon residue (polyurethane)
PlasmaWhirl™ Reactor processing Foundry Sand
PlasmaWhirl™ Reactor Bottom Feed Inlet
ArcWhirl™ Melter vitrified Shale Drill Cuttings

Cuttings provided by:
Carol Fleming
Chevron
Houston, Texas

Mark Arceneaux, VP
Gulf Coast Operations
CCS Energy Services
Slag (90% volume Reduction)
Can be used as
Cement Additive
Road Bed material
ArcWhirl™ Melter vitrified Lava Filter Media from Mine Water
Sample of oil shale from an outcrop of the Mahogany zone on the Piceance Creek Road near Rio Blanco CO.

Estimated average mineral composition of the Mahogany (from Baughman, ed., Synthetic Fuels Data Handbook, Cameron Engineers, Inc, 1978) is:

- 32% dolomite
- 16% calcite
- 15% quartz
- 19% illite (clay mineral)
- 10% albite (sodium feldspar)
- 6% potassium feldspar
- 1% pyrite (iron sulfide)
- 1% analcite (Na-silicate zeolite)
Oil Shale Sample Melt Test performed on October 3, 2007

Weight = 640 grams  Crushed then Weighed 1 lb
Oil Shale Sample Melt Test performed on October 3, 2007

Vitrified weight = 11 ounces (wt reduction = 32%)
2 minutes at 80 volts x 130 amps = 10,400 kva/30 = 347 watts = 1,185 BTUs/lb

Arc Heat Input = 1,185 BTUs/lb with ZERO heat recovery
power factor = .85, then out of wall power = 409 watts/lb
Arc Rotates or Whirls around carbon crucible
Shell ICP

The Shell method involves placing 15 to 25 electrical heaters per acre in vertical wells and then heating the oil to the required temperature over a 2 to 3 year period. This slow heating causes the rock to release its oil, and a gas similar to natural gas. The major energy requirement is the electricity to heat the oil shale which is estimated at 250-300 kw-hr per barrel.¹

FPL PAGD™

FPL is working on an in situ process termed Plasma Assisted Gravity Drainage similar to SAGD used in oil sands. The process utilizes a novel plasma heater.

Goal: 68 kw-hr per barrel.

¹http://www.mines.edu/Research/PTTC/newsletters/volume%209/v9n3p5.html
Lack of shale porosity will not hinder the process
A Turbine purposely designed to treat water while gasifying and cogenerating heat/electricity and compressing gases using:

- Oil Shale
- Coal
- Coke
- Oil Sand
- Stranded Gas
- Heavy Oil

Coming Soon – January 2008

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PlasmaWhirl™ Technology Trailer

Arc Whirl Power Supply

Air Compressor
(50-60 psi for Plasma)

Plasma Whirl Power Supply

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ArcWhirl™ Disinfection and Sand Filter System

Cosmic Rays
Gamma Rays
X-Rays
UV
Visible Light
Infrared
Radio Waves

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ArcWhirl™ Melter with Tank

Residual Baking Soda + Caustic Soda
Foret Plasma Labs Locations

Edmonton
Alberta

Buffalo
New York

Houston
Texas

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Foret Plasma Labs Demonstration Facility Location

252 Mc Carty Drive, Houston, TX  77029

www.qesc.com

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