The power of teamwork

MPPE: Macro Porous Polymer Extraction System
Why MPPE for FLNG?

1. Introduction / safety moment

2. Veolia Water

3. MPPE Technology & MPP Systems

4. Why MPPE for FLNG?

5. Shell Prelude MPPE unit

6. Where are we now?
History of Veolia Environnement

1853
Founding of Compagnie Générale des Eaux (CGE)

1875
Founding of Compagnie Générale Française de Tramways

1985
Forerunners of multiservice contracts

1998
CGE becomes Vivendi

1999
Vivendi Environnement created

2005
A new single name, Veolia
**Four businesses serving the environment**

<table>
<thead>
<tr>
<th><strong>VEOLIA ENVIRONNEMENT</strong></th>
<th>29,6 milliards d’euros de chiffre d’affaires Plus de 331 000 collaborateurs dans 77 pays</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water</strong></td>
<td>The global benchmark for water services €12.6 billion</td>
</tr>
<tr>
<td><strong>Waste management</strong></td>
<td>The global benchmark for waste management and resource recovery €9.7 billion</td>
</tr>
<tr>
<td><strong>Energy services</strong></td>
<td>The global benchmark for energy optimization €7.3 billion</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td>The global benchmark for sustainable mobility €8 billion (perimeter Veolia Transdev)</td>
</tr>
</tbody>
</table>
VWS industrial activities

- **Added value** for our customer through our unique knowledge, technologies and services

- **Provide sustainable solutions** from standard equipment to turnkey installation in order to **minimize customers’ environmental footprint**

- **Worldwide competences** and experience on many capabilities

- **Market segments**
  - Automotive
  - Biofuels
  - Chemicals
  - Exploration & production
  - Food & Beverage
  - Hydrocarbon processing
  - Oil & Gas (Upstream & Downstream)
  - Pharmaceuticals
  - Primary metals
  - Power
  - Pulp & Paper

---

**Capabilities**
- Process Water
- Produced Water
- Wastewater
- Sludge & biosolids
- Air & Gas
- Control & Instrumentation
- Services

---

**Examples**
- Formosa Heavy Industry (Philippines)
- Turbomach (Spain)
- Chevron San Ardo (United States)
VWS municipal activities

- **Ability to carry out large projects** from proposal to completion
- International network of local BU with **long term partnership**
- **Quick reactivity** and close working relationship combined with a **large technologies portfolio** allowing us to work with:
  - Major cities
  - Coastal & Tourist area
  - Rural municipalities

**Capabilities**

- Drinking Water
- Wastewater
- Sludge & biosolids
- Air & Gas
- Control & Instrumentation
- Services

Qingdao Maidao (China) Calgary (Canada) Burj Khalifa lake – Dubai (UAE)

MPP SYSTEMS

Lucien Grand (France)
Creating Water Solutions for the UPSTREAM OIL & GAS Industry
Integrated approach ensuring quality, safety, reliability
Why MPPE for FLNG?

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Removal of Dissolved and Dispersed Hydrocarbons

from
Offshore Produced Water,
Wastewater,
Process water,
Groundwater,

with Macro Porous Polymer Extraction (MPPE)

by
VWS MPP Systems B.V.
www.vwsmppsystems.com
MPPE

MPP Structure

MPP SYSTEMS
MPPE process (1)

Extraction

Condensed steam recycle

Water/hydrocarbons

Condensor

Water

Steam

Settler

Stripping

Hydrocarbons
MPPE process (2)

Organics & Water → Condensed water recycle

Extraction → Polymer

Stripping → Polymer

Condenser → Heavy Organics for reuse, Light Organics for reuse, Clean water

Steam
MPPE Extraction versus AC-adsorption

- Toluene supersedes Benzene
- More “other” molecules requires more Activated Carbon
- Sensitive for fouling

- Molecules do not “see” each other
- More “other” molecules require not more MPPE
- Not sensitive for fouling
## Components removable with MPPE

### Aromatic and Aliphatic Compounds
- Benzene
- Toluene
- Ethyl Benzene
- Xylene(s)
- Cumene
- Limonene
- Nitrobenzene
- Higheralkylated phenols
- Octanol
- Nonanol
- Decanol
- Hexane
- Heptane
- MIBK
- TetraHydroTiophene
- CS₂
- Tetramethyltetrahydrofuran
- MTBE
- Etc.

### Halogenated/Chlorinated Compounds
- Monochloromethane
- Dichloromethane
- Trichloromethane
- Tetrachloromethane
- Dichloroethane (1,1 & 1,2)
- Trichloroethane
- Tetrachloroethane
- Chloroethylene
- Dichloroethylene
- Trichloroethylene
- Tetrachloroethylene
- Trichloropropane
- Chlorobutadiene
- Hexachlorobutadiene
- Monochlorobenzene
- Dichlorobenzene
- Chlorobenzenes
- Chloropicnic acid
- Chloroanthalene
- Hexachlorocyclohexane
- Monochlorophenol
- Dichlorophenol
- Trichlorophenol
- Dichloro-di-isopropylylether
- Dioxins
- Etc.

### Polyaromatic Hydrocarbons
- PCBs
- Acenaphthylene
- Acenaphthene
- Fluorene
- Anthracene
- Fluoranthe
- Pyrene
- Benz(a) anthracene
- Chrysene.
- Etc.

### NPDs
- Naphtalenes
- Phenanthrenes
- Dibenzothiophenes
MPPE Features
Flexibility/ Robustness

- High reduction factor
- Reduction factor independent of inlet concentration
- Robust against water environment (surfactants, salts, pH range 3 - 9 etc.)
- Predictable performance
- Flow/ Inlet concentration flexibility
  - 10% lower flow: 50% higher inlet concentration possible
  - lower inlet concentration: higher flow possible
- Capacity flexibility
  - turn up / down ratio e.g. 0 to 150% of design capacity
- Batch wise operation; Immediate performance at start up
- Separated hydrocarbons (~ 100% pure) for (re)use
- No waste stream, no air emission
- 100% recovery of water and hydrocarbons

MPP SYSTEMS
Markets / Applications

- Industries
  - Offshore
  - Oil & Gas
  - Petrochemical
  - Chemical
  - Pharmaceutical
  - Coatings
  - Electronics
- Government

- Offshore produced water : 25%
- Industrial waste water : 35%
- Groundwater / DNAPL : 40%

- Customers e.g.
  - TOTAL
  - Gaz de France
  - NAM (Shell/Exxon)
  - Statoil
  - Shell
  - Dupont
  - Degussa
  - Albemarle
  - AkzoNobel
  - Philips
  - Woodside
  - Western Refining
  - Inpex
  - BP
MPPE

Elf Aquitaine / Total / Vermilion Harlingen
gas produced water treatment

Dispersed oil and BTEX removal

Since June 1994
- Produced water offshore gas
- Condensed water from MEG unit
- Dissolved / disperse aromatics
  1,500 – 2,500 ppm $\rightarrow$ < 0.5 ppm
- Dispersed oil (aliphatics)
  160 – 350 ppm $\rightarrow$ < 0.5 ppm
- Flow 4 m³/hr

Since June 1997
- Produced water offshore gas
- Condensed water MEG unit
- Rainwater / fun off water
- Groundwater
- 6 m³/hr

Column size (m): $d = 0.8, h = 2.0$
AkzoNobel / Organon (Merck SD) groundwater treatment 1994

- Oss (NL)
- Pharmaceutical RM supplier
- 40 m$^3$/hr
- Aromatics, chlorinated (250 ppm)
- Effluent < 0.5 ppm
- Iron 48 ppm, Ca 65 ppm
- Since December 1995
MPPE groundwater Lenoir (USA)
Two years of intensive testing
Five MPPE units, LMBV, Schwarze Pumpe Germany

- Groundwater since 2004
- 20 m³/hr
- BTEX 233,000 µg/l (ppb)
- Naphthalene 500 µg/l (ppb)
- PAHs 153 µg/l (ppb)
- > 99% removal
- Performance guaranteed
Two MPPE units, LMBV, Lauchhammer Germany

- Groundwater Dec. 2010
- 3 m³/h
- BTEX 30,000 → 150 ppb
- PAK 500 → 15 ppb
- Performance guaranteed
Germany plant Ruhrgebiet
Groundwater 120 m³/h
MPPE treatment of Tank Cleaning water with waste / ground / surface water
MPPE Western Refining Gallup USA

3D model Western Refining USA
MPPE unit, built in USA,
start up for April 2012
MPPE System Gaz de France (France)

- Underground gas storage
- Processwater
- 3 m³/hr (13 gpm)
- THT (odour)
- 50 → 0.5 ppm
- > 99% removal
- Since 2001
Why MPPE for FLNG?
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5. Shell Prelude MPPE unit
6. Where are we now?
North East Atlantic / North Sea
- 1978: 40 ppm dispersed oil (PARCOM)
- 2007: 30 ppm dispersed oil (OSPAR)

Individual countries

The Netherlands: Reduction Benzene / Aromatic discharge
- 1994: Benzene / Aromatic reduction of 80% in 2000
- 1998: NOGEPA study 55 technologies (MPPE Number 1)
- 1999: NAM offshore fieldtest L2 (OTC paper)
- 2002 / 2003: First commercial offshore MPPE units TOTAL; NAM
MPPE

NAM (Shell/Exxon) offshore MPPE field test 1999
MPPE

NAM (Shell/Exxon) offshore MPPE field test 1999
MPPE Offshore Demo unit
Since January 2002
- Produced water from offshore gas
- Removal of dispersed and dissolved Aliphatics, Aromatics, and PAHs
- Robust against salt, surfactants, corrosion inhibitors
- Fulfilling TOTAL's environmental goal beyond present legal requirements
- Remote controlled to enable unmanned operation
- To save space the MPPE unit is installed partially over the platform edge
MPPE remote control
North East Atlantic / North Sea (OSPAR)
- 1978: 40 ppm dispersed oil (PARCOM)
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Individual countries
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Norway
- Environmental Impact Factor (EIF)
### Oil & Gas produced water composition

<table>
<thead>
<tr>
<th>Hydrocarbons</th>
<th>Non polar</th>
<th>More polar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersed oil</td>
<td>Alphatics: 200-1000 ppm</td>
<td>Negligible</td>
</tr>
<tr>
<td>Floating (sheen)</td>
<td>Separators / flotation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Standard”: 40 ppm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Advanced”: 10-30 ppm</td>
<td></td>
</tr>
<tr>
<td>Dissolved</td>
<td>Aliphatics</td>
<td>Alcohol/Methanol/Glycol</td>
</tr>
<tr>
<td>Not floating</td>
<td></td>
<td>Carboxylic acids</td>
</tr>
<tr>
<td>“non toxic”</td>
<td></td>
<td>Hundreds of ppm</td>
</tr>
<tr>
<td>Toxic</td>
<td>Aromatics</td>
<td>Alkyl Phenols</td>
</tr>
<tr>
<td>Carcinogenic</td>
<td>BTEX 200 – 3,000 ppm</td>
<td>Ten – Hundreds ppb</td>
</tr>
<tr>
<td>Mutagenic</td>
<td>PAHs 200 – 80,000 ppb</td>
<td></td>
</tr>
</tbody>
</table>

**MPP SYSTEMS**
## Produced Water composition

<table>
<thead>
<tr>
<th>Compounds</th>
<th>ppm</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dispersed oil</strong></td>
<td>200 - 1,000 (gas)</td>
<td>DA</td>
</tr>
<tr>
<td><strong>Dispersed hydrocarbons</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dispersed Aliphatics</strong></td>
<td>floating</td>
<td></td>
</tr>
<tr>
<td><strong>Dissolved hydrocarbons</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toxic:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Benzene</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>- Toluene</td>
<td></td>
<td>T</td>
</tr>
<tr>
<td>- Ethyl benzene</td>
<td></td>
<td>E</td>
</tr>
<tr>
<td>- Xylene</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>- PAHs and NPDs</td>
<td>0.2 - 80</td>
<td>PAHs</td>
</tr>
<tr>
<td>- Alkyl Phenols</td>
<td>0.1 - 0.2</td>
<td>APh</td>
</tr>
<tr>
<td>Aromatics</td>
<td>200 – 3,000</td>
<td></td>
</tr>
</tbody>
</table>

**Dissolved hydrocarbons**

**Readily Biodegradable**

**Polar:**

- Acids
- Alcohols (Methanol)

**MPP SYSTEMS**
Produced Water composition

**Compounds** | **ppm** | **Composition** | **Ospar**
--- | --- | --- | ---
Dispersed oil =  | 200 - 1,000 (gas) | DA | DA
Dispersed hydrocarbons = | | | |
Dispersed Aliphatics = floating | | | |

**Dissolved hydrocarbons**

Toxic:
- Benzene
- Toluene
- Ethyl benzene
- Xylene
- PAHs and NPDs 0.2 - 80
- Alkyl Phenols 0.1 - 0.2

**Aromatics 200 – 3,000**
- Benzene (B)
- Toluene (T)
- Ethyl benzene (E)
- Xylene (X)

**Dissolved hydrocarbons**

Readily Biodegradable

Polar:
- Acids
- Alcohols (Methanol)

**MPP SYSTEMS**
Environmental Impact Factor

- Investigation Norwegian Offshore Industry (esp. Statoil)
  - Impact of Individual compounds on Environment
- Type of molecules and concentration determine Impact on Environment
- More toxic molecules:
  - Higher multiplication factors to reflect environmental impact
- Environmental Impact Factor: specific molecules or groups of molecules are expressed in % of the total 100% Environmental Impact of that particular produced water stream in that particular environment
Produced Water composition

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<td>PAHs</td>
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<td></td>
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<tr>
<td>Dissolved hydrocarbons</td>
<td></td>
<td>Polar</td>
</tr>
<tr>
<td>Readily Biodegradable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polar:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Acids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Alcohols (Methanol)</td>
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<td></td>
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</table>

MPP SYSTEMS
Produced Water composition

<table>
<thead>
<tr>
<th>Compounds</th>
<th>ppm</th>
<th>Composition</th>
<th>EIF*(1)</th>
<th>EIF*(2)</th>
<th>EIF*(3)</th>
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<tbody>
<tr>
<td>Dispersed oil</td>
<td>200 - 1,000</td>
<td>DA</td>
<td>DA</td>
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<td>DA</td>
</tr>
<tr>
<td>Dispersed hydrocarbons</td>
<td></td>
<td>B</td>
<td>BTEX</td>
<td>BTEX</td>
<td>BTEX</td>
</tr>
<tr>
<td>Dispersed Aliphatics</td>
<td>floating</td>
<td>T</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dissolved hydrocarbons</td>
<td></td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissolved hydrocarbons - toxic</td>
<td></td>
<td>X</td>
<td>PAHs</td>
<td>PAHs</td>
<td>PAHs</td>
</tr>
<tr>
<td>- Benzene</td>
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<tr>
<td>Dissolved hydrocarbons - polar</td>
<td>hundreds</td>
<td>Polar</td>
<td>Methanol</td>
<td>Methanol</td>
<td>Methanol</td>
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<td>Readily Biodegradable</td>
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<tr>
<td>Polar</td>
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<td></td>
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<td></td>
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<tr>
<td>- Alcohols (Methanol)</td>
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* EIF = Environmental Impact Factor
<table>
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<tr>
<th>Compounds</th>
<th>ppm</th>
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<th>EIF*</th>
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<td>Dispersed oil</td>
<td>200 - 1,000 (gas)</td>
<td>DA</td>
<td>BTEX</td>
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<tr>
<td>Dispersed hydrocarbons</td>
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Dissolved hydrocarbons Toxic:
- Benzene
- Toluene
- Ethyl benzene
- Xylene
- PAHs and NPDs: 0.2 - 80
- Alkyl Phenols: 0.1 - 0.2

Dissolved hydrocarbons
Readily Biodegradable
Polar:
- Acids
- Alcohols (Methanol)

* EIF = Environmental Impact Factor
**Produced Water composition**

<table>
<thead>
<tr>
<th>Compounds</th>
<th>ppm</th>
<th>Composition</th>
<th>EIF</th>
<th>“Flotation”</th>
</tr>
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<td>Dispersed oil</td>
<td>200 - 1,000 (gas)</td>
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**Dissolved hydrocarbons Toxic:**

Toxic:
- Benzene
- Toluene
- Ethyl benzene
- Xylene
- PAHs and NPDs
- Alkyl Phenols

- Aromatics 200 – 3,000
- PAHs 0.2 - 80
- Alkyl Phenols 0.1 - 0.2

**Dissolved hydrocarbons**

Readily Biodegradable

Polar:
- Acids
- Alcohols (Methanol)

**EIF** = Environmental Impact Factor

MPP SYSTEMS
Compounds

Dispersed oil = Dispersed hydrocarbons = Dispersed Aliphatics = floating

Dissolved hydrocarbons Toxic:
- Benzene
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- PAHs and NPDs
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Dissolved hydrocarbons
Readily Biodegradable
Polar:
- Acids
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MPPE systems

* EIF = Environmental Impact Factor
Compounds ppm

Dispersed oil = Dispersed hydrocarbons = Dispersed Aliphatics = floating

Dissolved hydrocarbons Toxic:

Toxic:
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Dissolved hydrocarbons Readily Biodegradable

Polar:
- Acids
- Alcohols (Methanol)

*EIF = Environmental Impact Factor
## Composition produced water gas / condensate and oil

**Flow rates** (m³/h)
- Gas produced water: < 1 – 150 / 180
- Oil produced water: 100 – > 1000

**Inlet (ppm)**
- Aliphatic HC (dispersed oil): 200 – 1400 (484*)
- Aromatics (BTEX): 300 – 3000 (482*)
- PAHs: 4 – 80
- TPH: 700 – 4000

**Typical goals**
- Disp. oil: < 10 – 30
- BTEX: < 10
- PAHs: < 0.1 – 0.01
- TPH: < 10 – 30
- EIF: Zero Harmful

* Shell average offshore data Tekna 2012
1. GAS production: produced water after separator/degasser
2. Gas drying (glycol): MEG REGEN Produced water

A. 1 + 2  MPPE Process removal of:

1. Dispersed oil (aliphatics)  200 - 1.400 ppm:  > 99%
2. Dissolved and dispersed aromatics (BTEX)  300 - 3.000 ppm:  > 99%
3. PAHs  ppm - 4 - 80:  > 99%
4. Alkyl Phenols  ppb levels:  ~ 30%
5. Chemicals  ppb / ppm:  ~ 20 - 50%

B. Onshore, if desired Bio treatment to remove:
   Methanol, Glycol, Carboxylic acids, etc.
New Offshore Tie-ins and impact on On-Shore Facilities
Field Case Kollsnes

By Lars Bergersen and Jesper Jacobsson
Statoil
Statoil Kollsnes Phenomena

- Treating offshore Produced Water of 4 platforms
- Start up extra platform (Kvitebjørn)
  - Equal TOC levels!
  - Bioactivity ceased!
  - MPPE installed
  - Biotreatment recovered within three months
  - MPPE removes
    - Aliphatics (dispersed oil) > 99%
    - BTEX > 99%
    - PAHs > 99%
    - Alkyl Phenols ~ 30%
Equal TOC levels but Bio ceased?

20 – 100 times more and varying BTEX contents (up to 600 ppm)

10 – 50 times more PAHs and C₂ – C₄ Phenols

Poisoned biological mass

BTEX > 12 mg/l could be toxic to biological mass

Monitoring toxic content (BTEX, PAHs); not TOC
An MPPE unit was rented May 2005.
Statoil Kollsnes (Norway) produced water
StatoilHydro / Shell Ormen Lange (Norway) produced water
**Ormen Lange Project**
- World’s most challenging gas field development project
- Makes Norway world’s largest exporter of natural gas
- Largest industrial project ever carried out in Norway
- 100 kilometer from the northwest coast of Norway

**MPPE Unit removes the:**
- Dispersed oil (aliphatics)
- Dissolved and dispersed aromatics (BTEX)
- Poly Aromatics (PAHs)

- Flow rate 70 m$^3$/h
- > 99% removal of BTEX, PAHs, Aliphatics (oil)
- In operation since October 2007
MPPE

Survey Emission Regulations 3/3

- North East Atlantic / North Sea (OSPAR)
  - 1978: 40 ppm dispersed oil (PARCOM)
  - 2007: 30 ppm dispersed oil (OSPAR)

Individual countries
- The Netherlands: Reduction Benzene / Aromatic discharge
  - 1994: Benzene / Aromatic reduction of 80% in 2000
  - 1998: NOGEPA study 55 technologies (MPPE Number 1)
  - 1999: NAM offshore fieldtest L₂ (OTC paper)
  - 2002 / 2003: First commercial offshore MPPE units TOTAL; NAM

- Norway
  - Environmental Impact Factor (EIF)

- Australia
  - 2007: 50 → 30 ppm dispersed oil
  - 2009: Total Hydrocarbons < 30ppm (dispersed and dissolved)

- Egypt
  - 2012: Law 4 (PAHs: “ZERO”)

MPP SYSTEMS
Location Pluto LNG Burrup plant

- Burrup, Peninsula, Western Australia
Woodside Pluto (Australia) produced water
Inpex Ichthys project
Inpex Ichthys
MPPE unit

MPPE unit

MPP SYSTEMS
Contents presentation

Why MPPE for FLNG?
1. Introduction

2. Veolia Water

3. MPPE Technology & MPP Systems

4. Why MPPE for FLNG?

5. Shell Prelude MPPE unit

6. Where are we now?
MPPE unit for first Floating LNG plant in the world; Shell Prelude - Australia

Shell Prelude project
- First Floating LNG plant in the world
- FLNG technology reduces project costs and the environmental footprint of an LNG development
- Delivery April 2013
- Direct discharge after MPPE treatment

MPPE for removal of:
- Dissolved and dispersed oil (aliphatics)
- Dissolved and dispersed aromatics (BTEX)
- Poly Aromatic Hydrocarbons (PAHs)
- Flowrate: 140 m³/h
- Removal of BTEX, PAHs, Aliphatics (oil)

MPP SYSTEMS
Shell Prelude Floating LNG

- Treatment + liquefaction
- 488m x 74m: largest floating structure
- Avoids: pipelines, coastal modifications, land use
- Lower environmental footprint
- Flexibility to relocate and reuse
- For “stranded” gas assets
- A game changer
Vendor Engagement Meeting
MPPE

Shell Prelude MPPE unit

MPP SYSTEMS
Shell Prelude MPPE unit
“Why MPPE for FLNG”

- Removal of toxic content (Oil, BTEX) for Zero Harmful Discharge
- Separation performance independent of inlet concentration (peak loads!)
- Robust against water environment (surfactants, inhibitors, chemicals)

- Recovered hydrocarbons ready for use as a product
- 100% Recovery of separated hydrocarbons and water
- No waste stream
- Remote controlled
MPPE performance in offshore produced water

<table>
<thead>
<tr>
<th></th>
<th>Influent levels ppb</th>
<th>Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas / Condensate / LNG</strong></td>
<td></td>
<td></td>
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<tr>
<td>BTEX (dissolved/dispersed)</td>
<td>300,000 – 3,000,000</td>
<td>&gt; 99%</td>
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<tr>
<td>Aliphatics (dispersed oil)</td>
<td>100,000 – 1,300,000</td>
<td>&gt; 99%</td>
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<tr>
<td>PAHs</td>
<td>200 – 80,000</td>
<td>&gt; 99%</td>
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<tr>
<td>Alkyl Phenols</td>
<td>14,000</td>
<td>~ 30%</td>
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<tr>
<td>Field chemicals, inhibitors</td>
<td>ppm levels</td>
<td>20 – 50%</td>
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<tr>
<td>Environmental Impact Factor</td>
<td></td>
<td>95 – 99%</td>
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</table>

<table>
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<tr>
<th><strong>Oil</strong> (Total, NAM, StatoilHydro)</th>
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<tbody>
<tr>
<td>BTEX</td>
<td>30,000 – 70,000</td>
<td>&gt; 99%</td>
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<tr>
<td>Aliphatics (dispersed oil)</td>
<td>13,500 – 40,000</td>
<td>80 – 95%</td>
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<tr>
<td>PAHs</td>
<td>500 – 2,100</td>
<td>&gt; 99%</td>
</tr>
<tr>
<td>Alkyl Phenols</td>
<td>ppb levels</td>
<td>~ 30%</td>
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<tr>
<td>Environmental Impact Factor</td>
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<td>&gt; 85%</td>
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MPPE robustness (2): Surfactants (NAM)

(1) steam restriction
(2) surfactant spill

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<tr>
<th>Date</th>
<th>BTEX concentration (µg/l)</th>
<th>BTEX (influent) %</th>
<th>BTEX (effluent) %</th>
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<td>98%</td>
<td>81%</td>
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<td>96%</td>
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<td>3/16/99</td>
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<td>4/16/99</td>
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<td>93%</td>
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<td>4/20/99</td>
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<td>94%</td>
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<td>94%</td>
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<td>5/17/99</td>
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<td>99.6%</td>
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</tr>
</tbody>
</table>
Why MPPE for FLNG?

1. Introduction

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MPPE observed Mercury Removal

- NAM offshore field test 1999 (OTC paper)
- Bench Mark studies 2011
- Cadmium, lead, nickels: 0.0001 – 0.014 ppb
- Mercury inlet: 3 – 120 ppb
- Cases with removal %
  a. 5 years: 81 – 85 %
  b. 8 years: > 92%
  c. 9 years: 98 – 99.0 %
  d. 10 years: 83 – 98 %
Future MPPE: Shale oil

MPP SYSTEMS
Future MPPE: Shale gas

An Elusive Prize | Many nations are believed to have large shale deposits

Note: Data are shown only for countries included in the survey. Figures are estimates. Source: U.S. Energy Information Administration

MPP SYSTEMS
Questions?