

Electric Flowline Heating Explained



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- ▶ Why Use EFH?
- ▶ How Does EFH Work?
- ▶ EFH System Types
- ▶ Design Methodology
- ▶ Choosing a System
- ▶ Typical EFH Equipment
- ▶ EFH Installations to Date

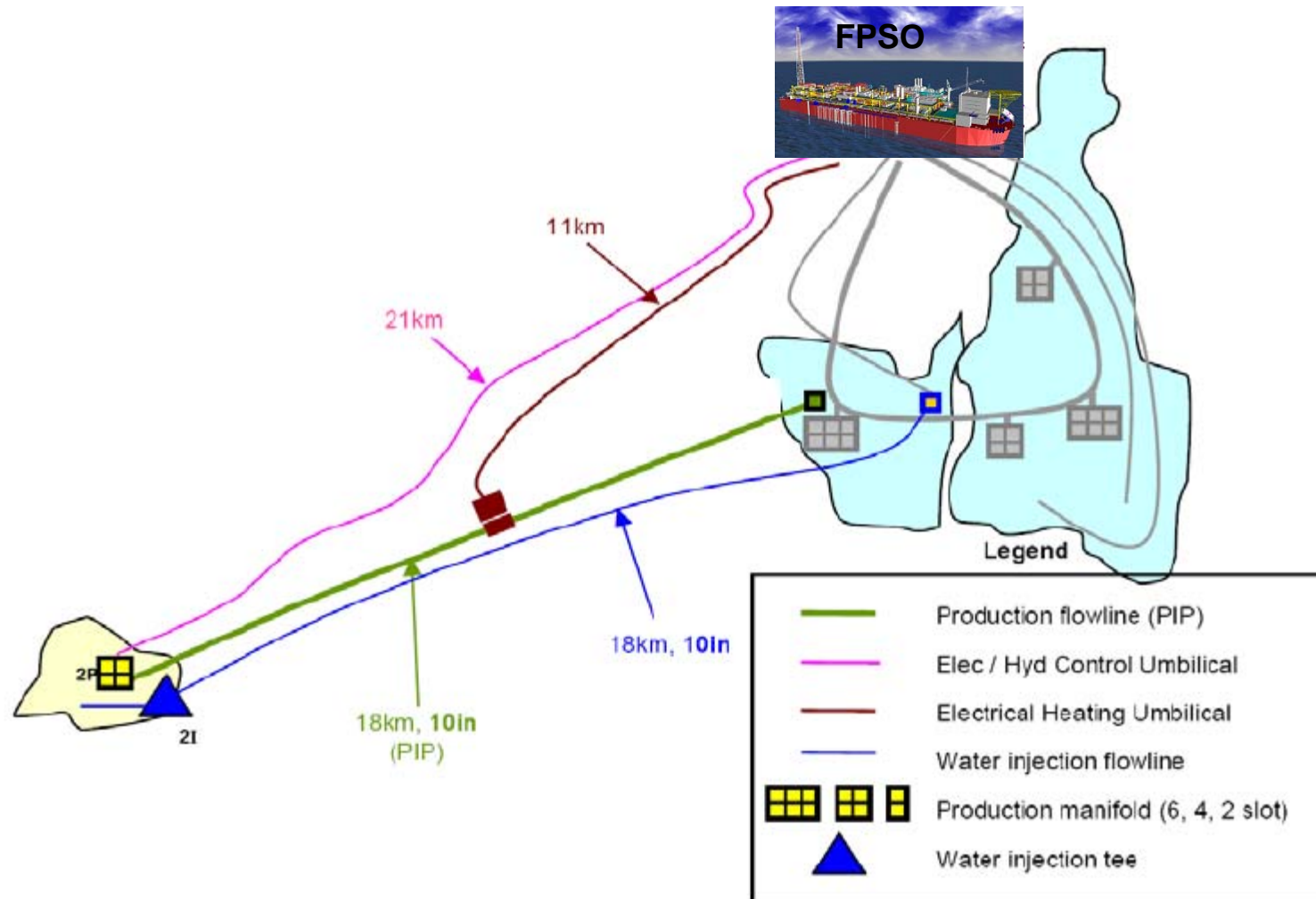
Two Words: Flow Assurance

- ▶ Prevent hydrate & wax formations
 - Deepwater
 - Long tie-backs
 - Shut downs
 - Tail end production periods
 - Third-party tie-ins

- ▶ Reliable, environmentally friendly alternative to chemical injection



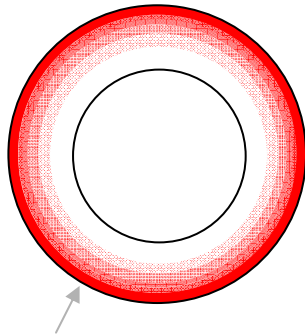
Field Development Enabler



How does EFH Work?

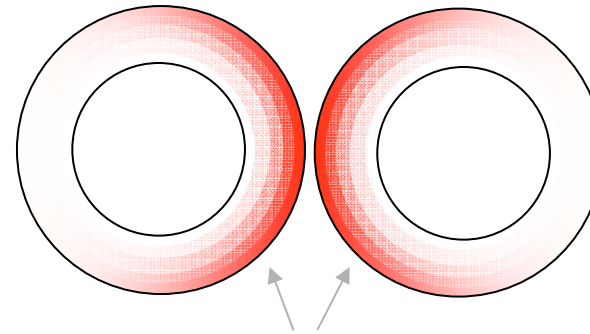
- ▶ EFH heat \geq heat lost to surroundings
- ▶ Current through a conducting material generates heat using material's AC resistance: $P_e = I^2 R_{ac}$
- ▶ Material's AC resistance is increased by SKIN and PROXIMITY effects.

Skin Effect



Current flow tends towards outer surface of conductor

Proximity Effect



Current flow tends towards surfaces in close proximity

- ▶ Heating is enhanced b/c of high current density on surfaces.

EFH System Types

Direct Electric Heating (DEH)

Electric current flows axially through the pipe wall causing direct heating of the pipeline.

Wet-insulated

- Open Loop System

Dry-insulated

- End-Fed Pipe-in-pipe
- Center-Fed Pipe-in-pipe

Indirect Electric Heating

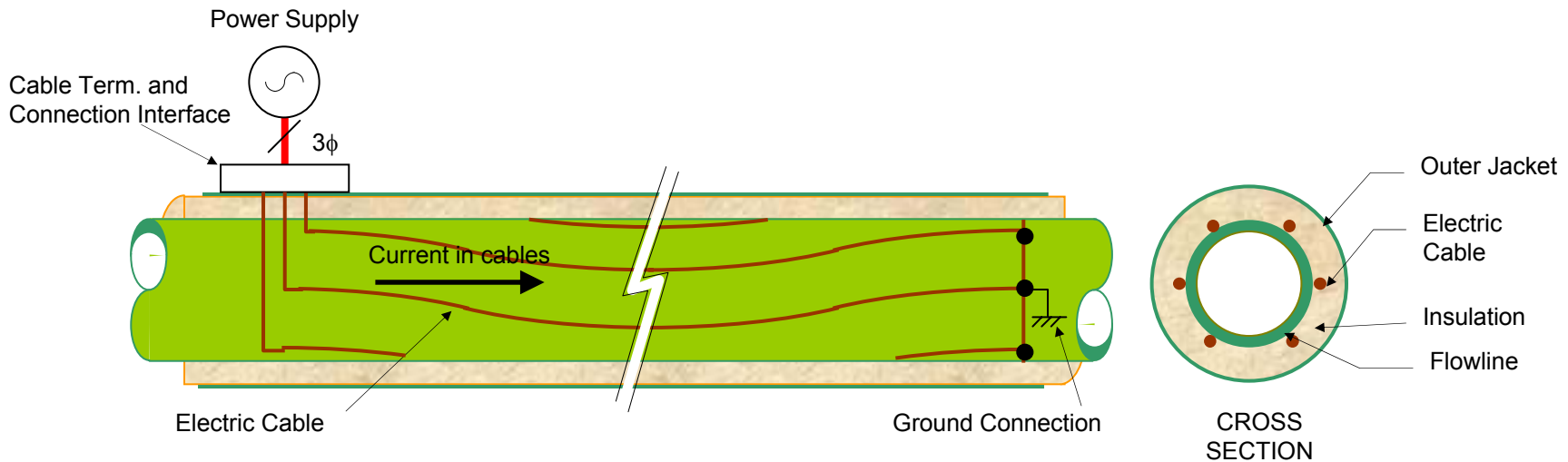
Electric current flows through a heating element on the pipe surface. The flowline is heated through thermal conduction.

- Cable Heating
- Induction Heating
- Tube Heating

Terminology: DEH vs. EFH

- ▶ DEH stand for Direct Electrical Heating (of flowlines).
- ▶ EFH stands for Electrical Flowline Heating.

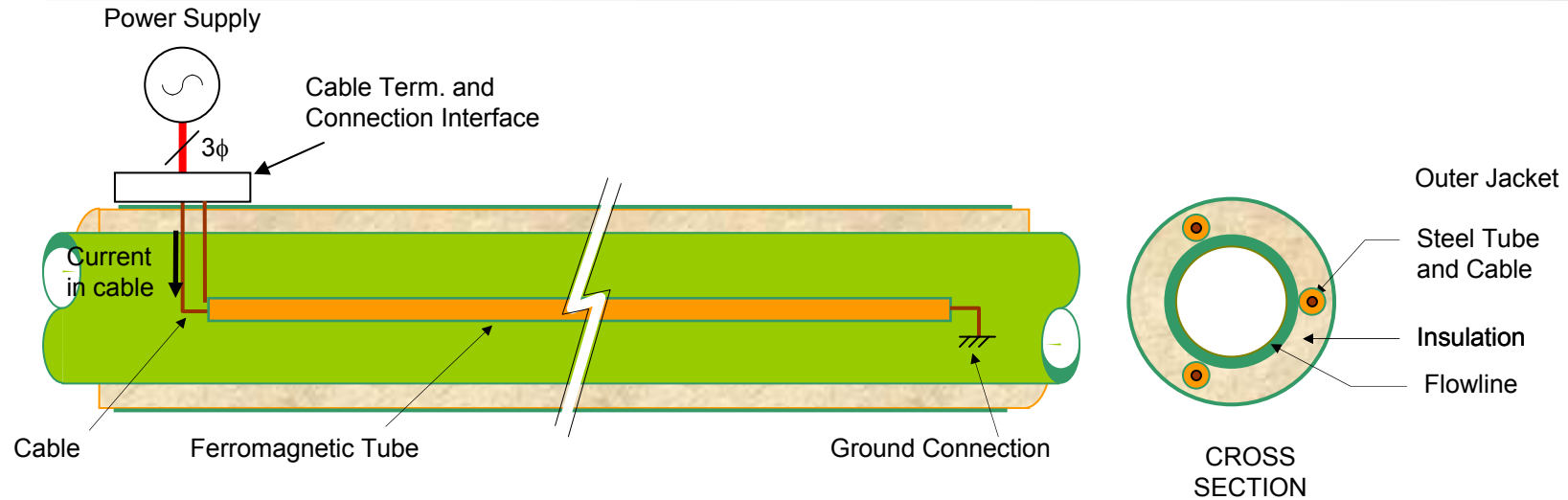
- ▶ Both terms are commonly used interchangeably, which can lead to some confusion.
- ▶ DEH is traditionally associated with the Wet Insulated flowline heating system technology.
- ▶ EFH is traditionally associated with the Dry Insulated (Pipe-in-Pipe) flowline heating system technology, but can also be used as a general reference to any flowline heating using electricity.



WEAKNESS: Limited heat output

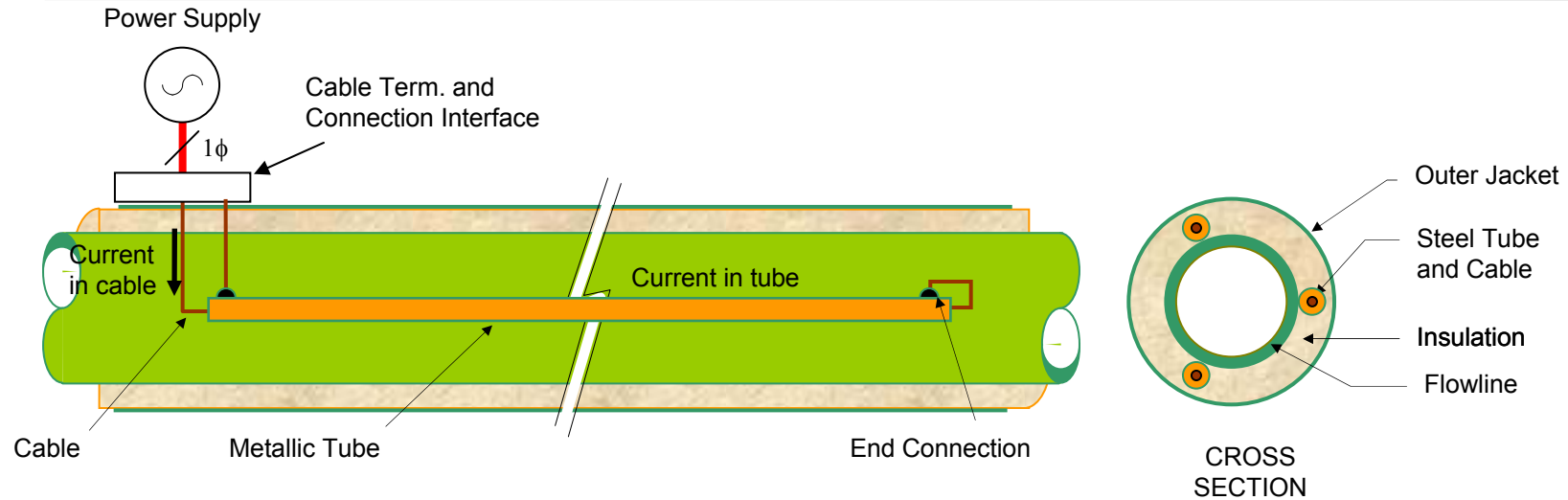
- Electrical cables are strapped to flowline.
- Current through the cables produces heat via resistance.
- Flowline is heated through thermal conduction.

Induction Heating



WEAKNESS: Poor thermal insulation

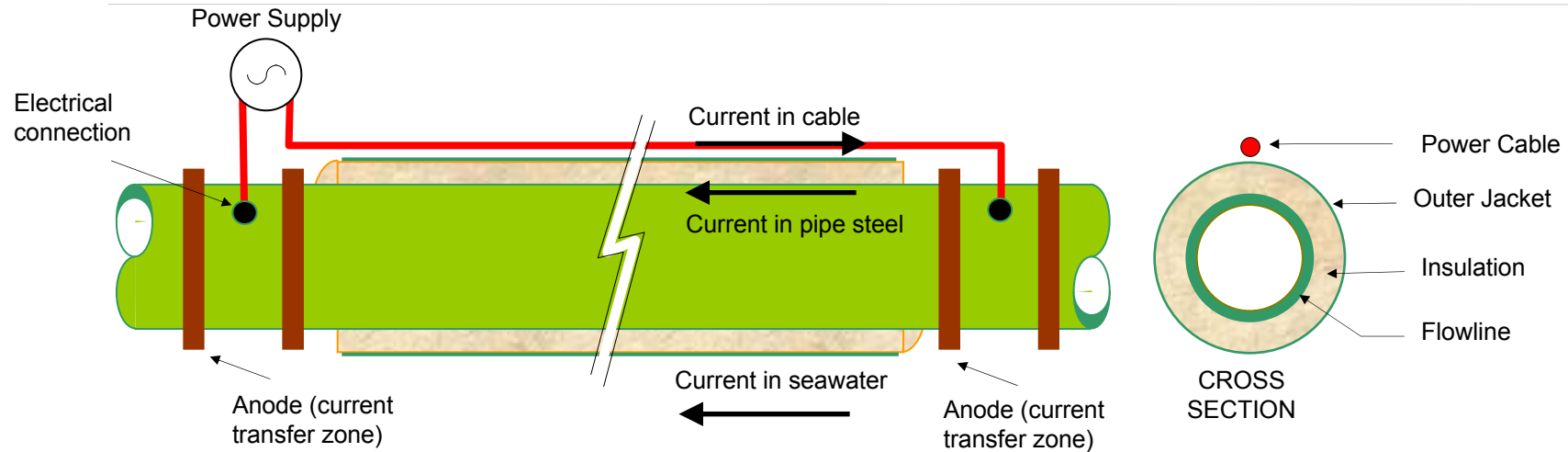
- Power cable inside steel tube is strapped to flowline.
- Current in the cable induces eddy currents in the steel tube, using resistance to produce heat.
- Flowline is heated through thermal conduction.



WEAKNESS: Poor thermal insulation

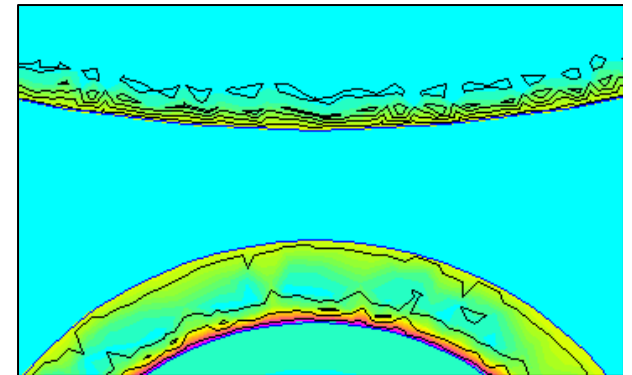
- Power cable inside steel tube is strapped to flowline.
- Steel tube is used as the return conductor, using resistance to produce heat.
- Flowline is heated through thermal conduction.

Wet Insulated Open Loop System

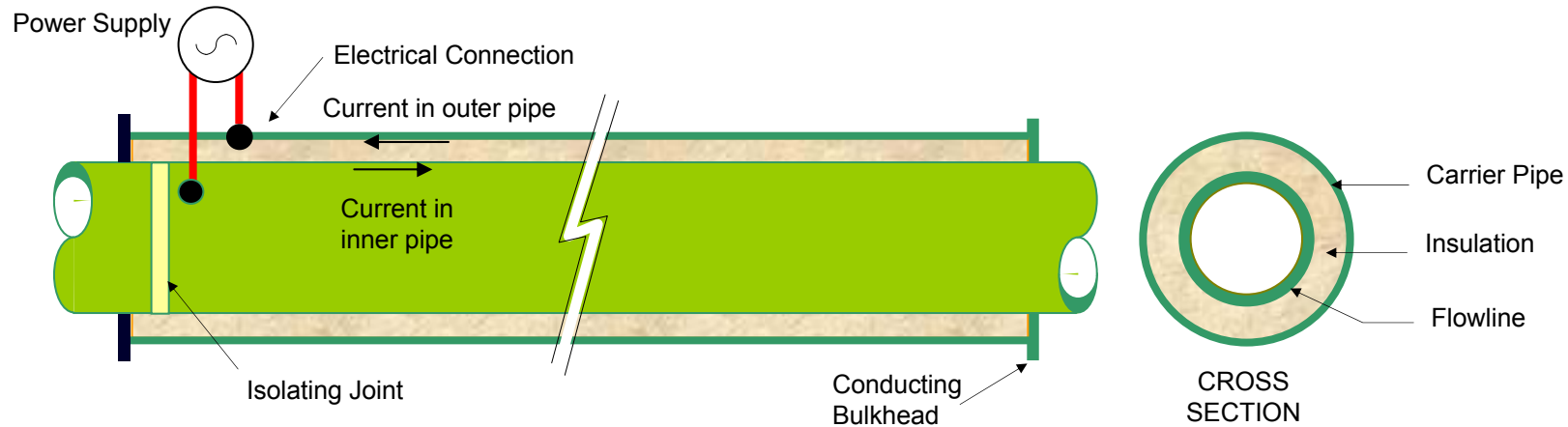


STRENGTH: No electrical insulation issues **WEAKNESS:** Low efficiency

- ▶ Single pipe with thermal insulation
- ▶ Current flows in cable and returns in pipe and seawater.
- ▶ Heating is along cable-to-pipe interface (proximity effect)
- ▶ Design consideration: Cathodic protection in current transfer zones
- ▶ Safety: Pipe and surroundings are at same potential, i.e. pipe is grounded to seabed

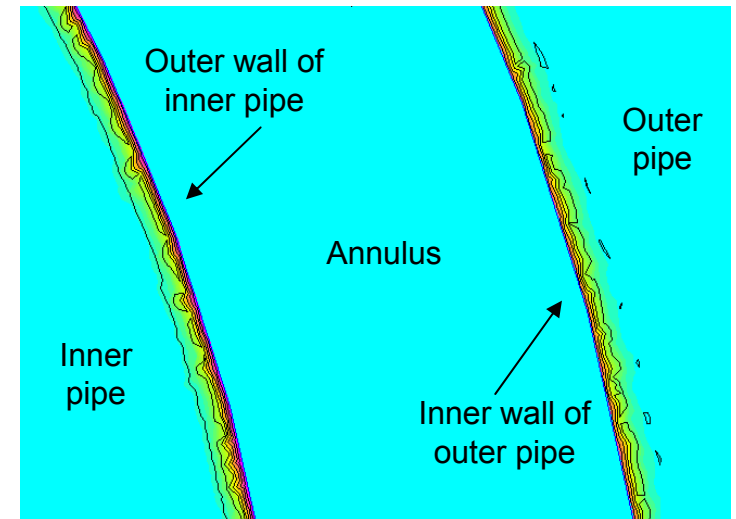


End-Fed Pipe-In-Pipe System



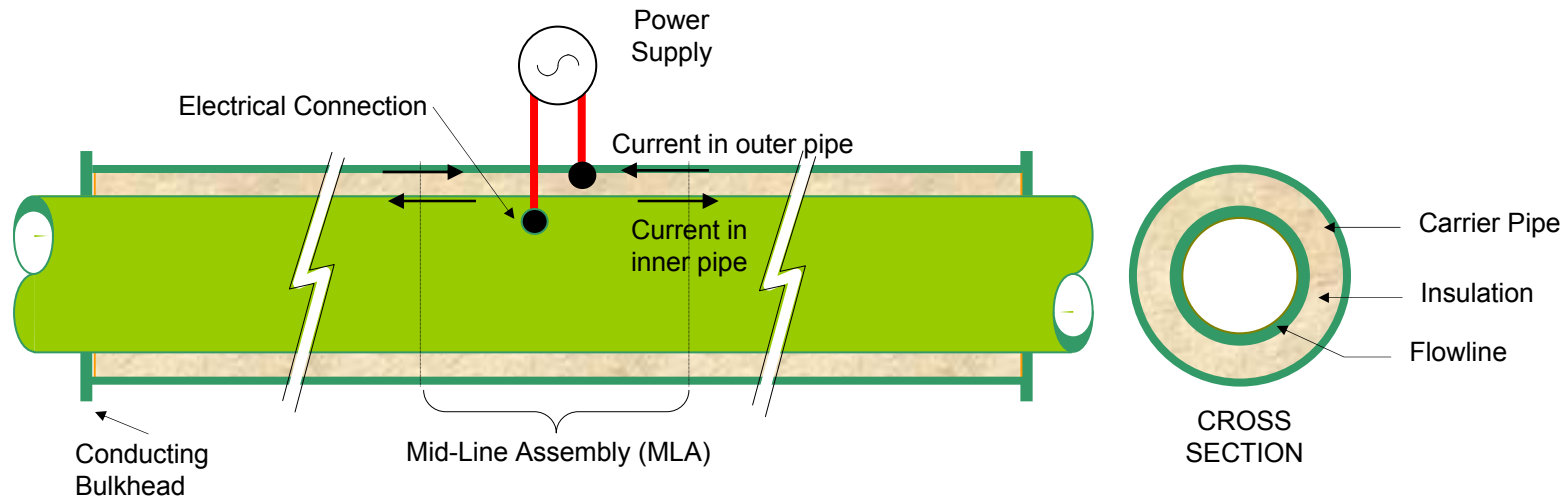
STRENGTH: High efficiency, low current **WEAKNESS:** Non-flowing conditions only

- ▶ Two concentric pipes with thermal and electrical insulating material in annulus
- ▶ Concentric construction promotes both skin and proximity effect heating.
- ▶ Power supply is connected at one end of the pipeline.



Current Density of PIP EFH

Center-Fed Pipe-in-Pipe System



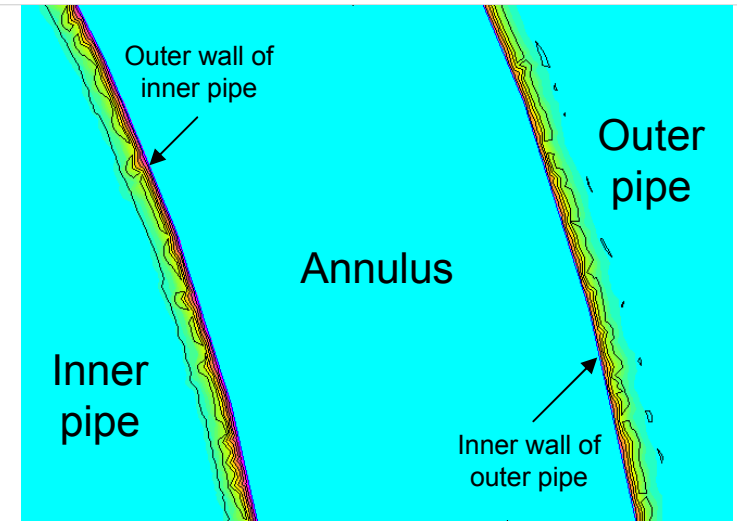
STRENGTH: High efficiency, low current **WEAKNESS:** Higher subsea equipment costs

- ▶ Two concentric pipes with thermal and electrical insulating material in annulus
- ▶ Power supply is connected at Mid-Line Assembly (MLA).
- ▶ Concentric construction promotes heating from both skin and proximity effects.
- ▶ Design consideration: Annulus voltage

Safety of PIP EFH

- ▶ Skin & Proximity effects nearly isolate current from product flow and seawater
- ▶ Minimal current flow on surface
- ▶ “Current takes path of least resistance”
(Actually, it splits based on resistance)

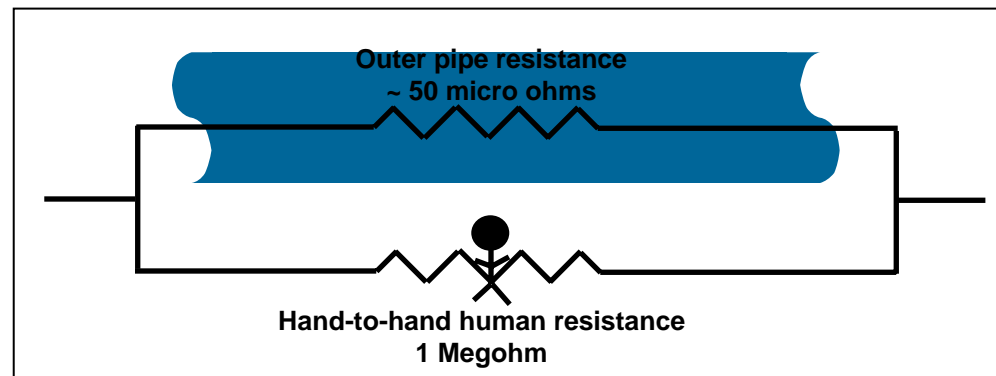
Human 1×10^6 ohms vs Outer Pipe $\sim 50 \times 10^{-6}$ ohms



Current Density of PIP EFH

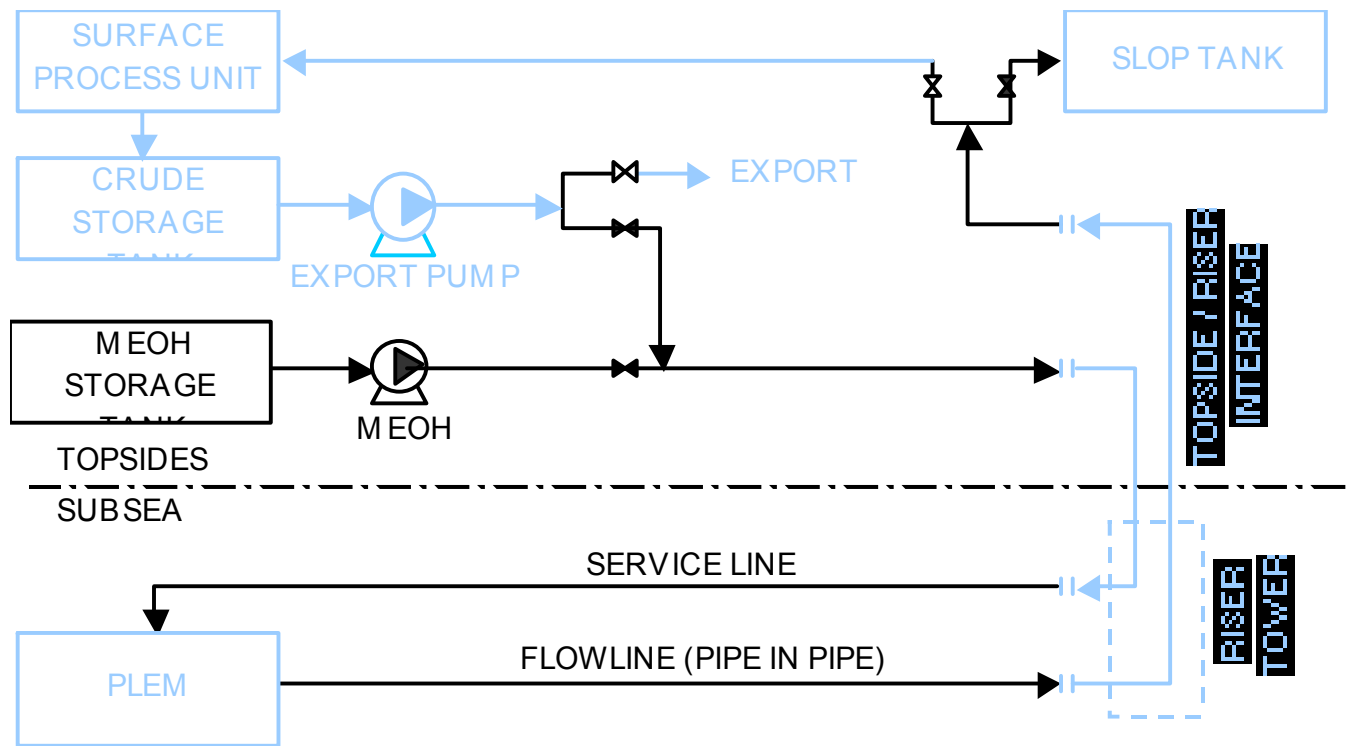
$$I_{\text{human}} = V * R_{\text{human}} = 0.014 \text{ micro amps}$$

(below level of perception)

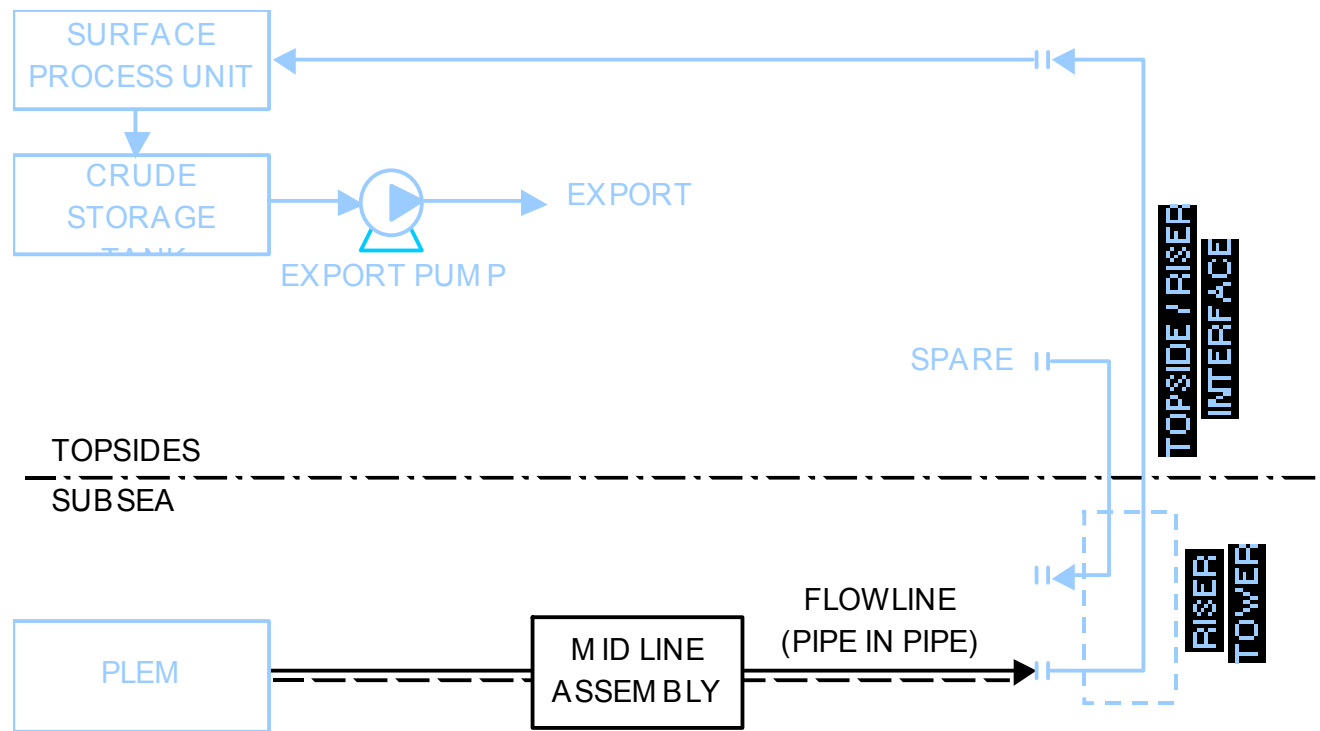


- ▶ Holistic, system-wide approach
- ▶ Pros and Cons must be weighed.
- ▶ Limitations must be considered.
- ▶ “Best system” is field-specific.

Flow Diagram – Conventional Flow Assurance



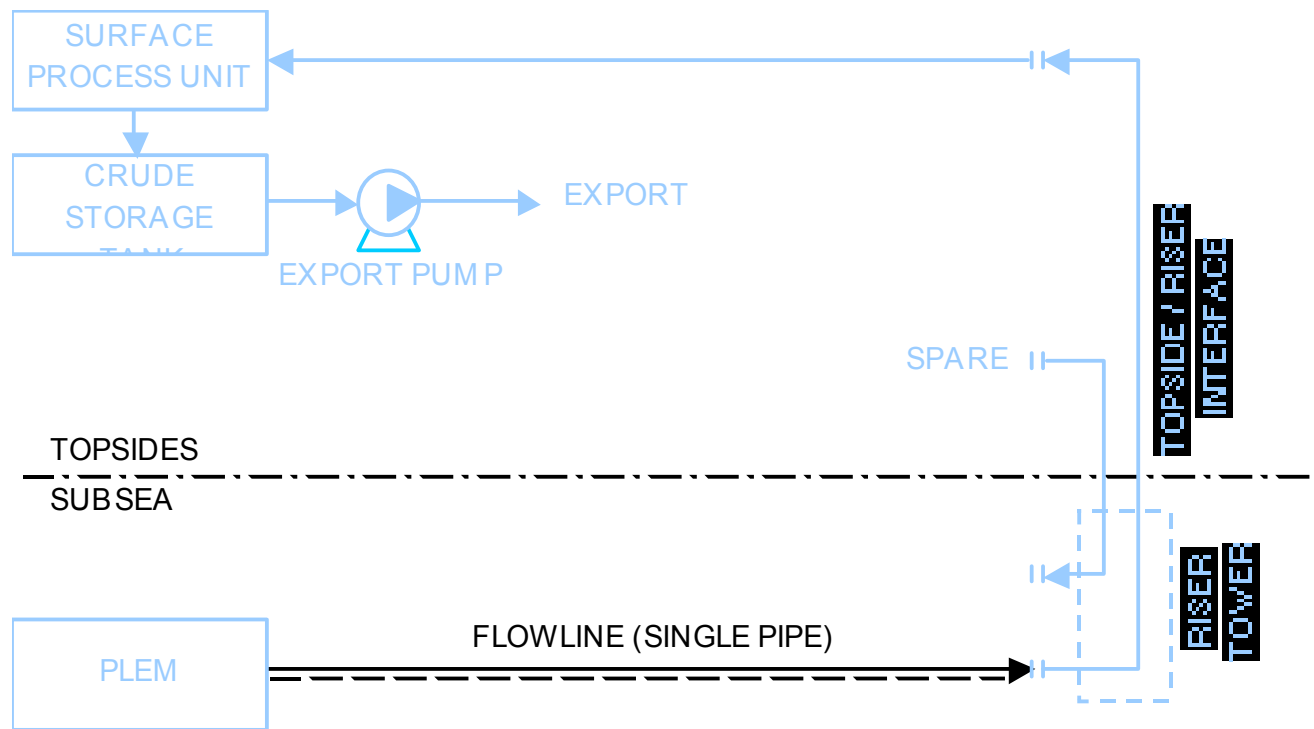
PIP (Center Fed) EFH



LEGEND

- INCLUDED IN ESTIMATE
- NOT INCLUDED IN ESTIMATE
- - - ELECTRIC HEATING

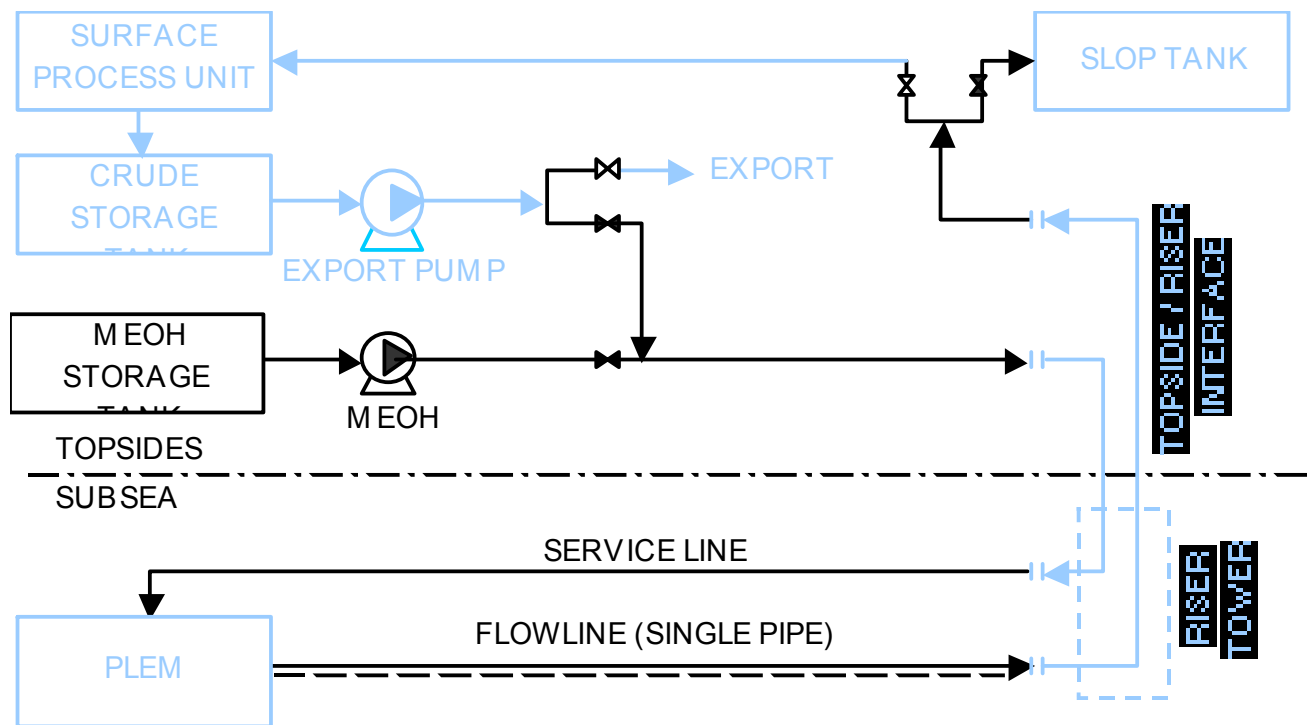
Open Loop EFH



LEGEND

- INCLUDED IN ESTIMATE
- NOT INCLUDED IN ESTIMATE
- - - ELECTRIC HEATING

Open Loop EFH + Conventional FA



LEGEND

- INCLUDED IN ESTIMATE
- NOT INCLUDED IN ESTIMATE
- - - ELECTRIC HEATING

Choosing a System - Comparison

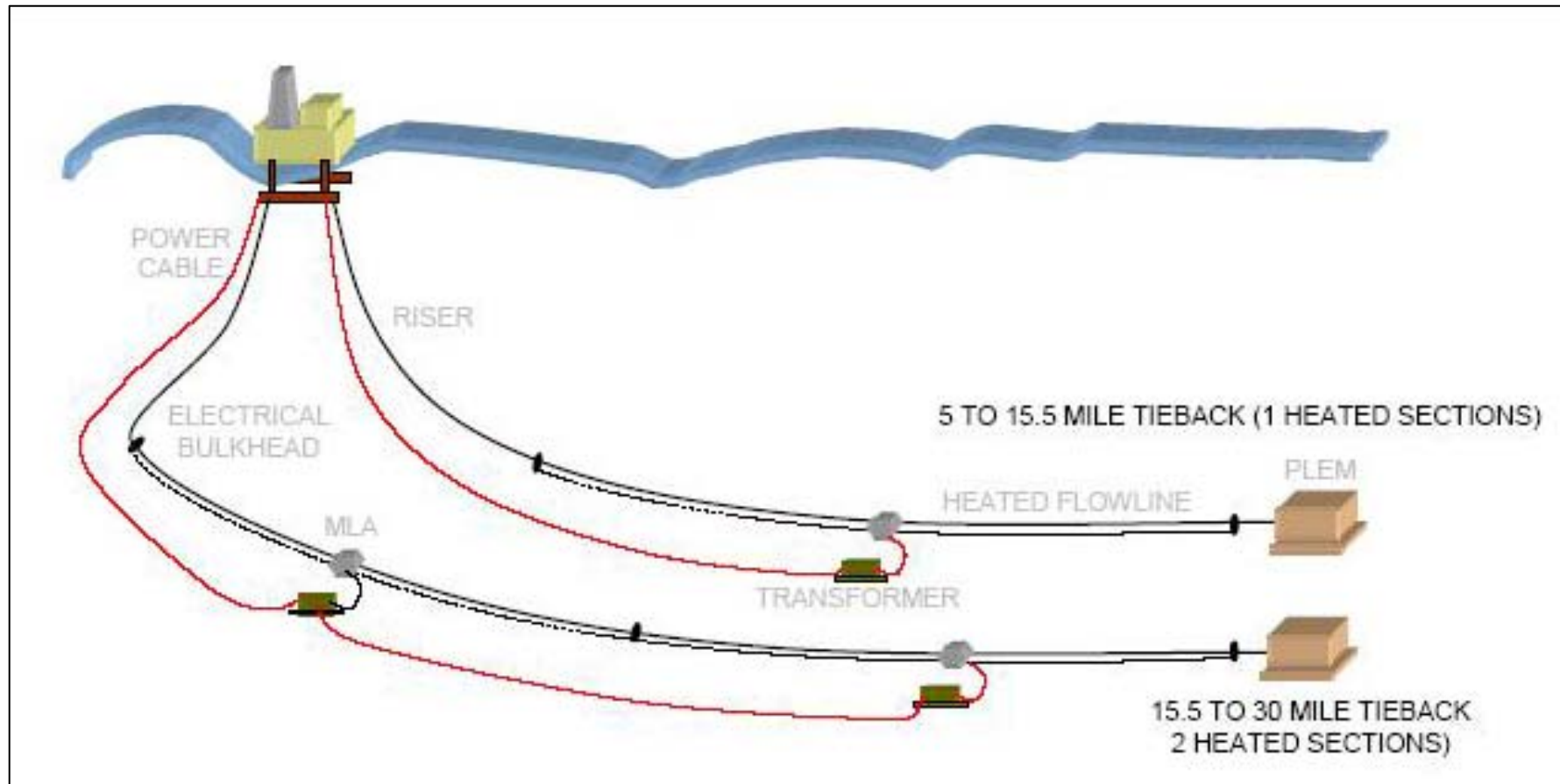
CAPEX and OPEX Costs of EFH, Conventional Flow Assurance, and combined solutions for previous example pipeline:

DESCRIPTION	PIPE IN PIPE FLOWLINE OPTION			SINGLE PIPE FLOWLINE	
	CONVENTIONAL FLOW ASSURANCE	FED) ELECTRIC HEATING	PIP (CENTRE FED) EH + CONV FA	OPEN LOOP ELECTRIC HEATING	OPEN LOOP EH + CONV FA
FLOW ASSURANCE					
<u>FA Technique</u>					
- MeOH	√	-	√	-	√
- Dead Oil Displacement	√	-	√	-	√
- Electric Heating	-	√	√	√	√
<u>EH Duty</u>					
Start-up Heating	-	√	√	√	√
Production - Temp. Maint.	-	-	-	√	√
Shutdown - Temp. Maint.	-	√	√	√	√
COST ESTIMATE (Flowline & Flow Assurance)					
CAPEX (\$ MM)	37.9	30.5	42.3	23.5	35.3
OPEX (\$ MM) <small>(12 year, 4 shutdowns/year)</small>	6.4	0.1	0.1	6.0	6.0
TOTAL (\$ MM) <small>(life of field cost)</small>	44.3	30.6	42.4	29.5	41.3
DELTA COST (Comparison with Conventional FA Solution)					
CAPEX (\$ MM)	-	-7.4	4.4	-14.4	-2.6
OPEX (\$ MM) <small>(12 year, 4 shutdowns/year)</small>	-	-6.3	-6.3	-0.4	-0.4
TOTAL (\$ MM) <small>(life of field cost)</small>	-	-13.7	-2.0	-14.8	-3.0

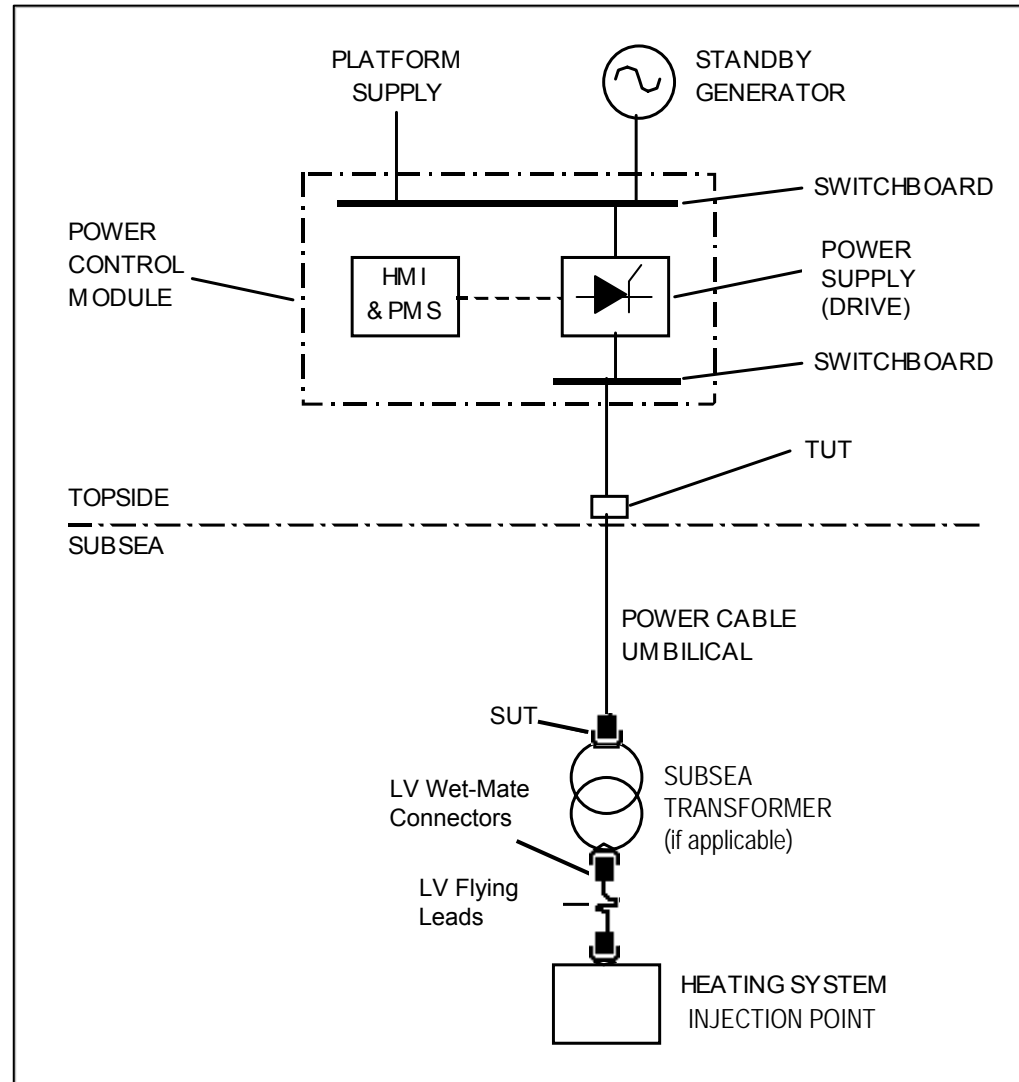
(System diagrams on following slides)

1. Determine heating load requirements (W/m)
2. Perform power cable design (for open or closed system)
3. Analyze model of system via electromagnetic FEA to determine electrical requirements
4. Perform anode system design (for open system)
5. Determine requirements of major components:
 - topsides power module
 - power cable
 - subsea transformer (if applicable)
 - wet- and dry-mate connectors
 - mid-line assembly (for center-fed PIP)

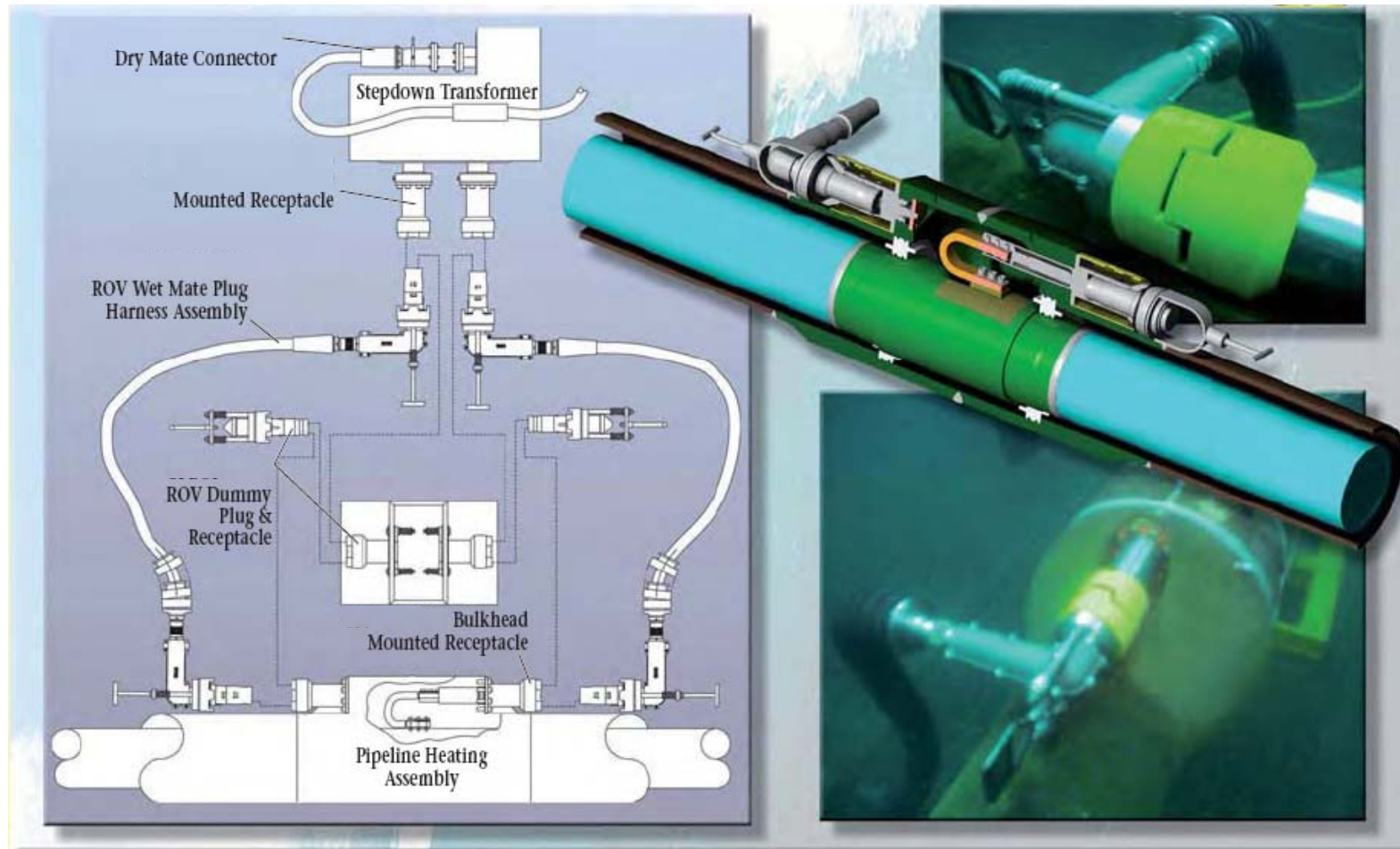
Typical EFH Electrical Equipment



Typical Center-Fed PIP EFH Electrical Equipment



Current injection point used in center-fed PIP EFH systems

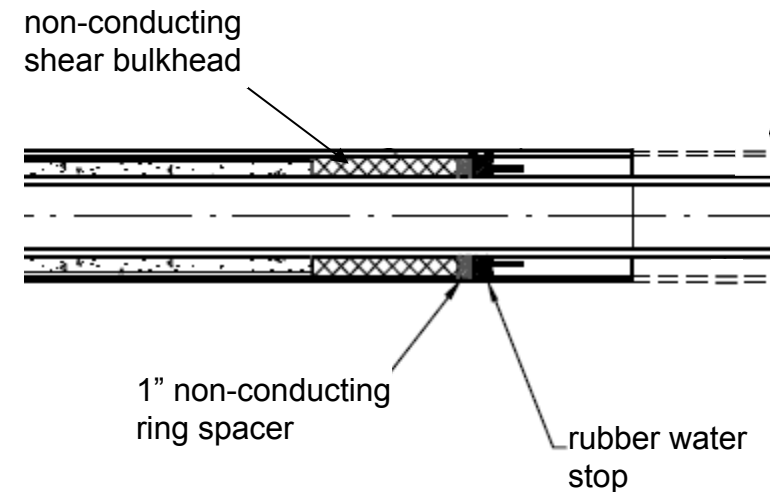


EFH PIP Annulus

- ▶ Electrical shorts from inner to outer pipe must be avoided.
- ▶ Any material which may bridge annulus must be non-conducting.

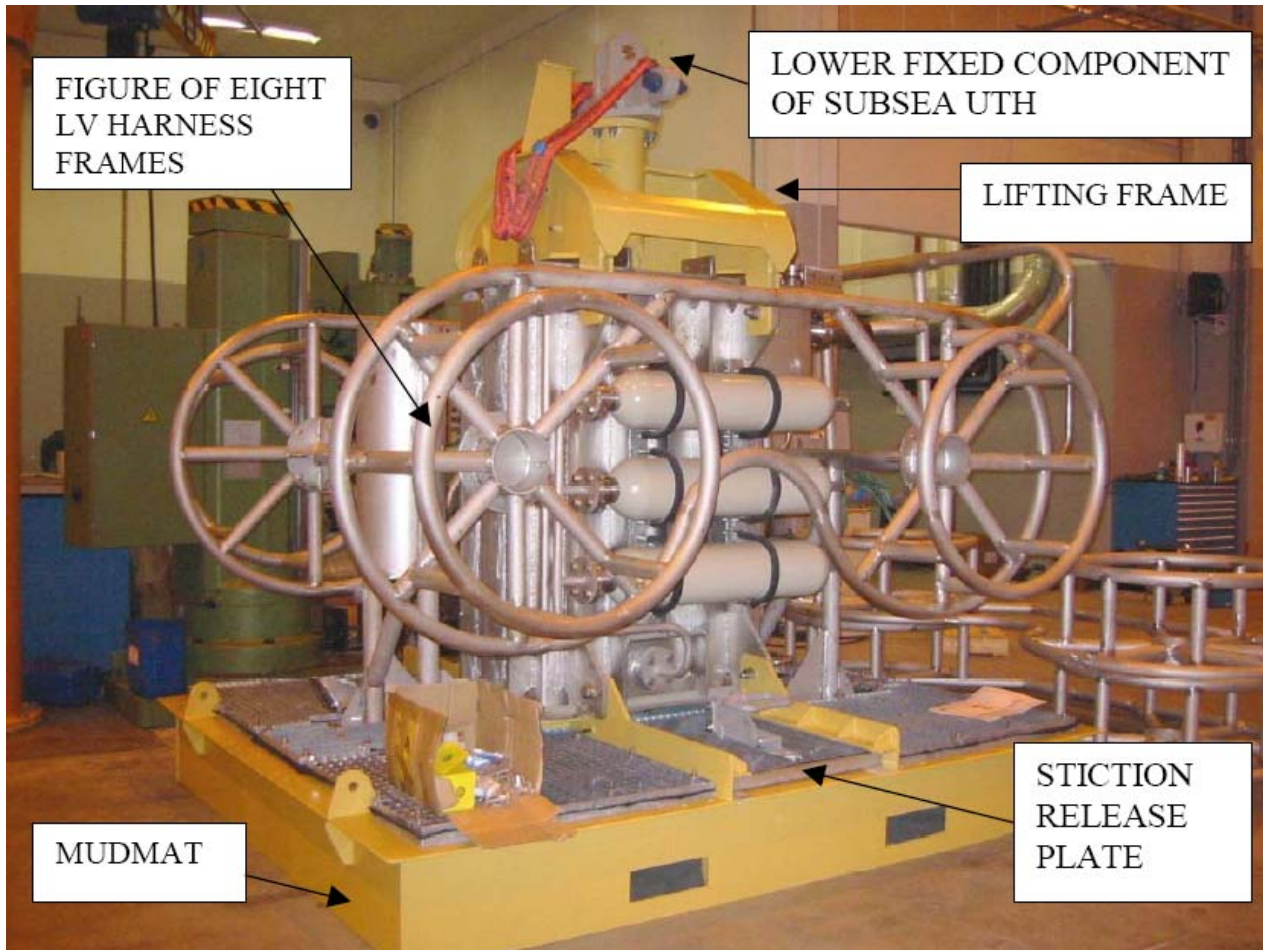


Pouring of non-conducting shear bulkheads



Non-conducting water stops

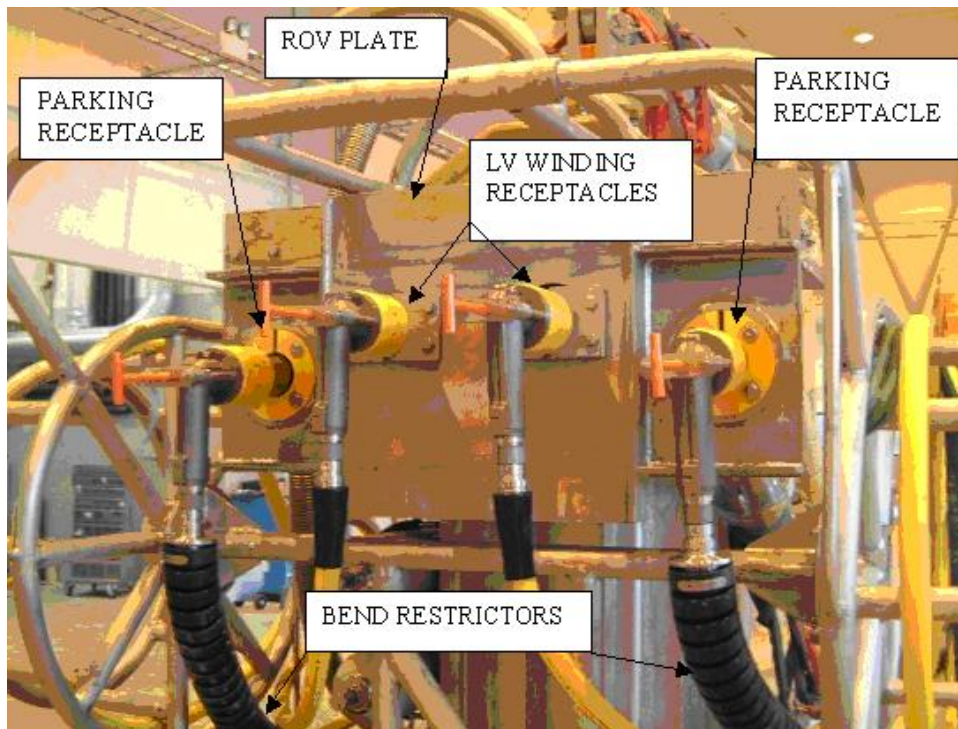
Subsea Transformer



The need for a SS transformer is determined by the distance to the current injection point.

Subsea Transformer Connections

Connections of LV jumpers are typically wet-mate so that transformer can be installed separately from pipeline.



Low Voltage Wet-Mate Connectors in
Terminals & Parking Spots

Connections of HV cable to transformer can be dry-mate or wet-mate depending on system configuration and retrievability requirements.



High Voltage Dry-Mate Connector

- ▶ Open Loop
 - Statoil Asgard (2000)
 - 6 sections - 6-9km length each, 400m depth
 - Statoil Huldra (2002)
 - 16 km length, 400m depth, used >60 times
 - Statoil Kristin (2005)
 - 6 sections - 6-8km length each , 350m WD
 - Statoil Urd (2005)
 - 9km length, 400m WD
 - Statoil Tyrihans (2007)
 - 44km length, 150m WD
- ▶ PIP End-Fed
 - Shell Serrano and Oregano (2001)
 - Two 6x10" flowlines - 10 & 12km, 1000m WD
- ▶ PIP Center-Fed
 - Shell/BP Nakika (2004)
 - 10x16", 6 sections - 1.9-13km each, 1700-2100m WD
 - Shell Habanero (2003)
 - Two 6x10" Flowlines, 16km length, 750m WD