Innovative Steam Technologies

Power and Energy

Once-Through Heat Recovery Steam Generators

Alex Berruti, P. Eng

WISE Talk

University of Waterloo

April 24, 2018

Presentation Overview

- *IST Company / OTSG Origins*
- *OTSG technology*
- *OTSG Engineering Challenges*
- *Engineering Tools*
- *Innovation - Enhanced Oil Recovery OTSG*
- *Innovation - Organic Rankine Cycle OTSG*
- *Future Challenges*

Innovative Steam Technologies

we find a better way

IST Company & OTSG Origins

Company Profile

- IST founded – 1992 Cambridge – On, Canada
- Sales to date >200 OTSG's
- 100 staff in Design, Engineering, Manufacturing and Service
- Sales Offices – Canada, Dubai, Korea

Company Profile

- Manufacturer of Once Through Steam Generator (OTSG) for the following industries:
  - Large Power Plants (Heat Recovery)
  - Manufacturing Facilities (Process Steam)
  - Small Power Plants (ORC Heat Recovery)
  - Enhanced Oil Recovery (Steam Injection)

The OTSG Origin

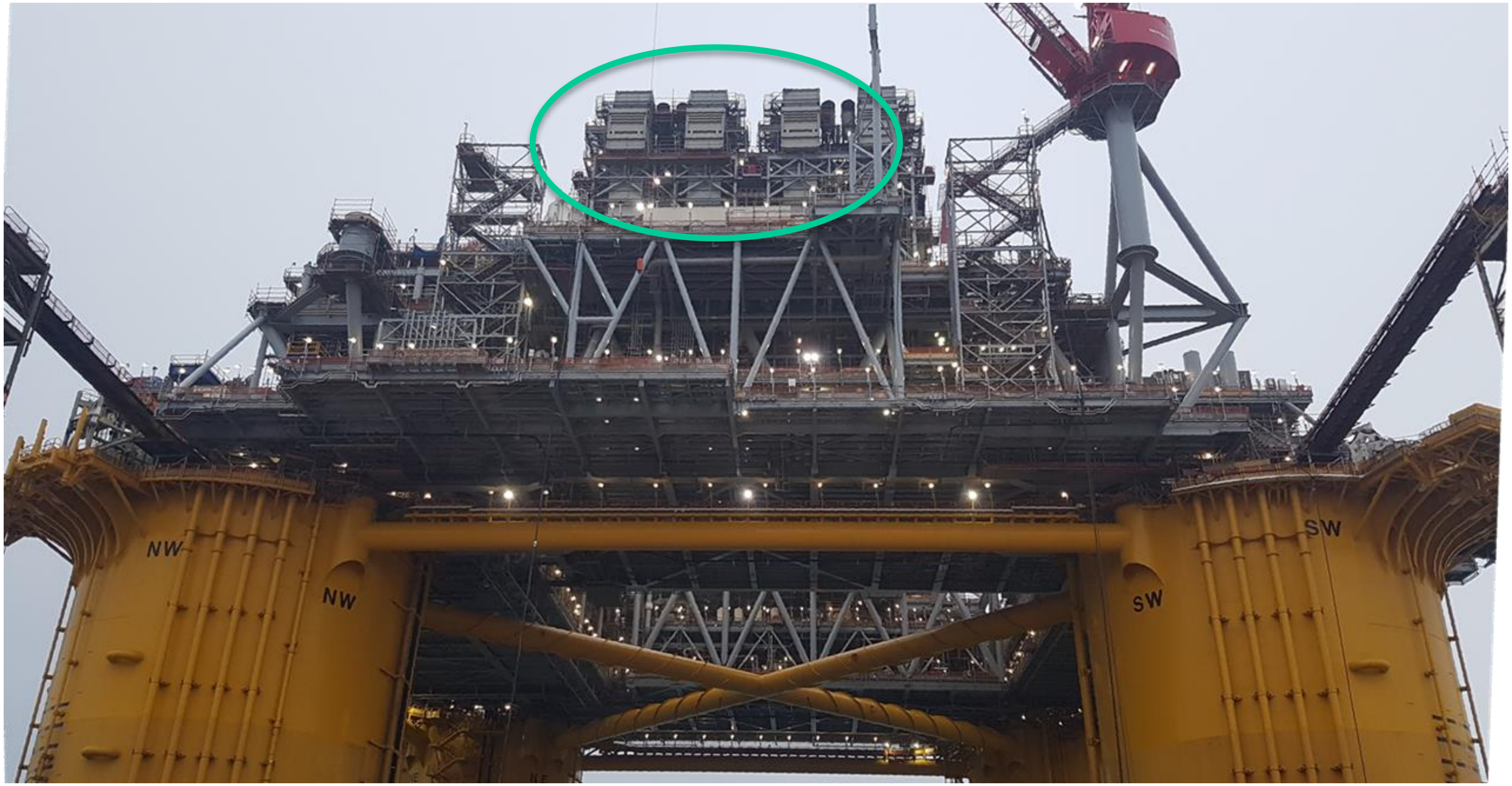
The Racer Program in the 1980's required a HRSG for offshore applications that was:

- Lighter
- Smaller
- Simpler
- Unaffected by the pitch and roll of the seas

Outcome was a Once Through Steam Generator

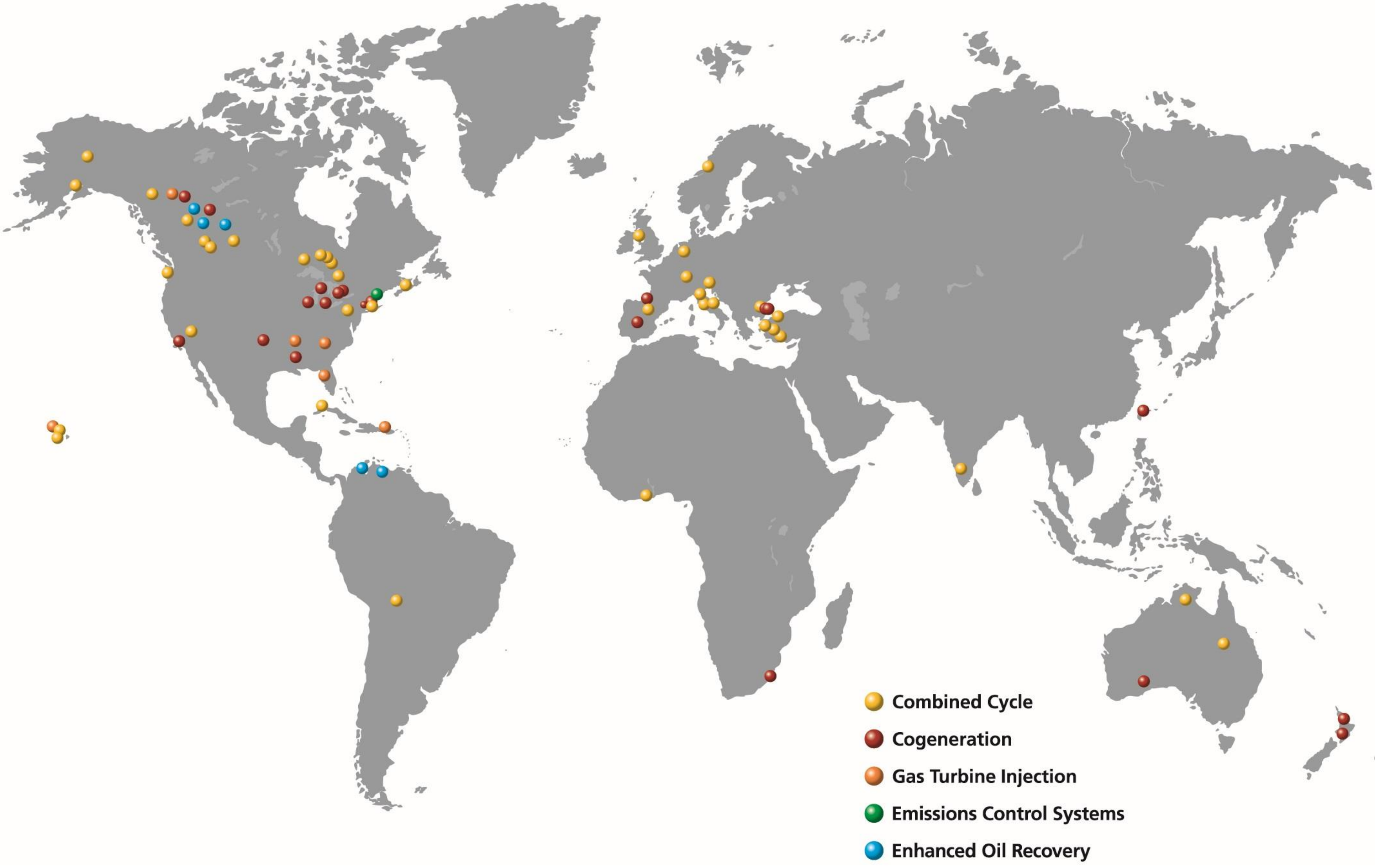
The Result: Ultra-Modular / Compact OTSG

Oil Platform – OTSG Power Generation



Shell / Appomattox Platform
175,000 bpd

" 2017 Shell Quality Award "



IST OTSG Installations Worldwide

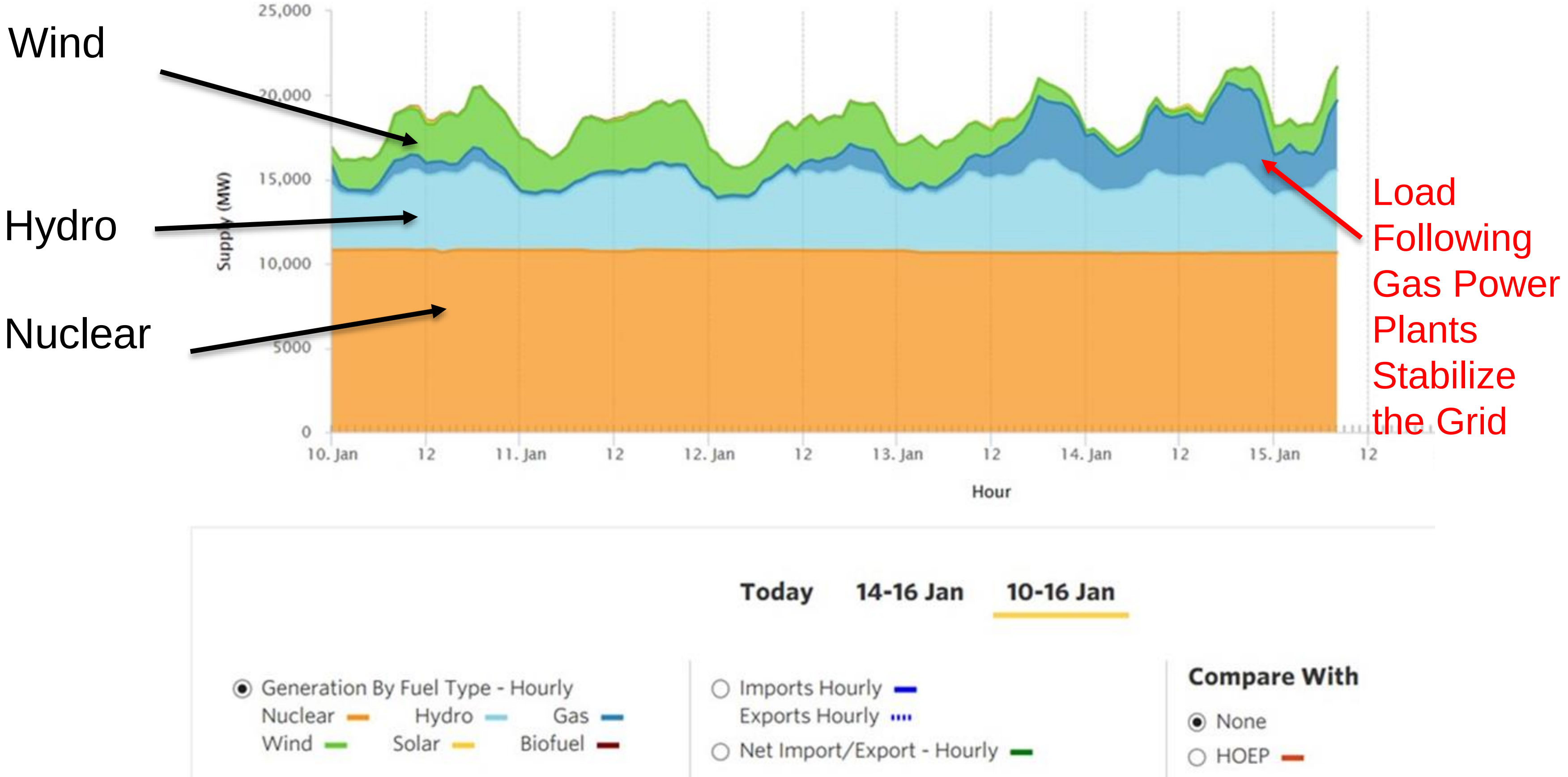
Innovative Steam Technologies

we find a better way

Canada (North America) Power Market

Ontario Power Generation (Daily)

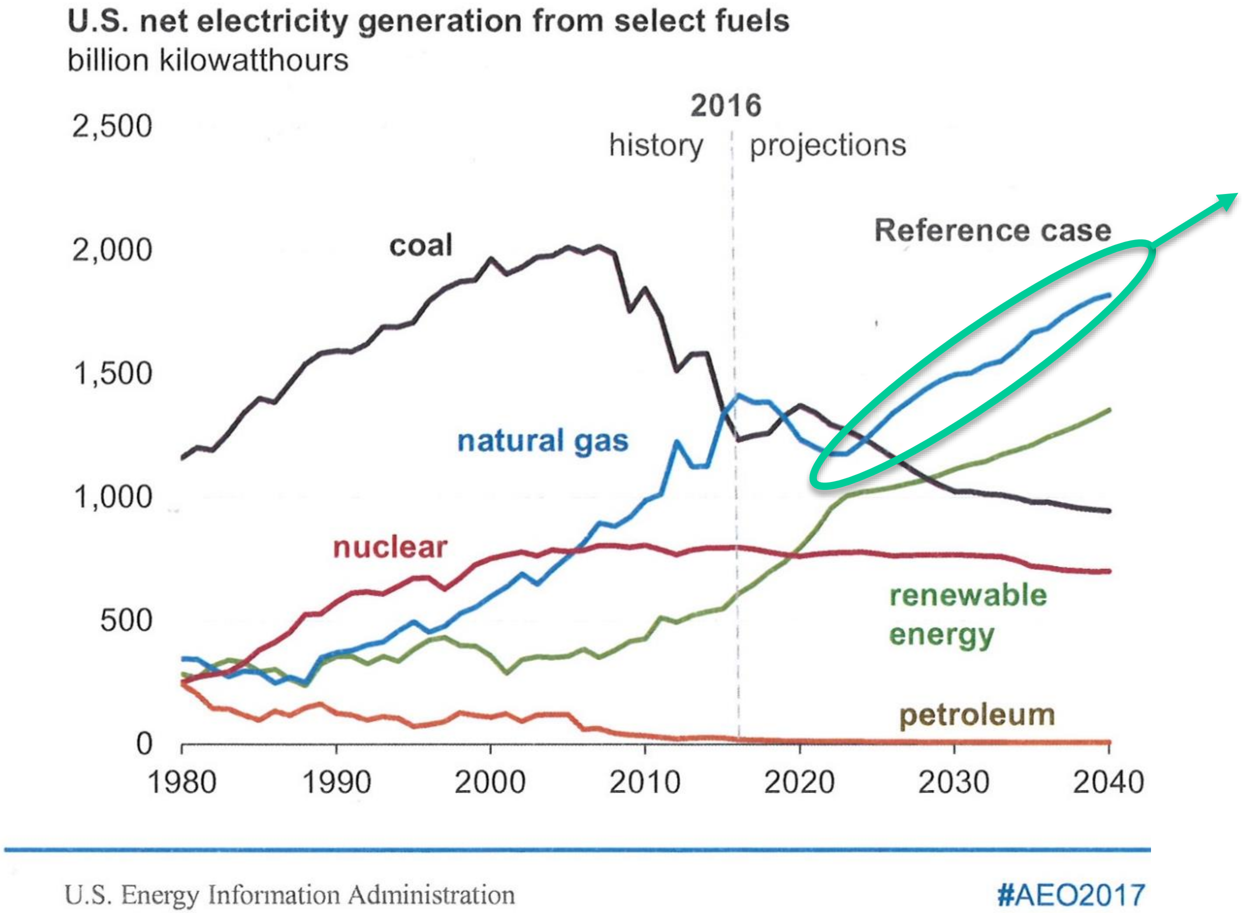
Renewables and Load Following - Ontario



[IESO – Ontario Power Supply]

Power Plant Opportunities – Renewables

Natural Gas ~~vs~~ and Renewables



Natural gas power plants to meet future electrical needs

** Power plants must be **load following** to match daily varying power demands

Waste heat recovery from gas power plants is key to **lower carbon** footprint and higher **efficiency**

IST Innovative Steam Technologies

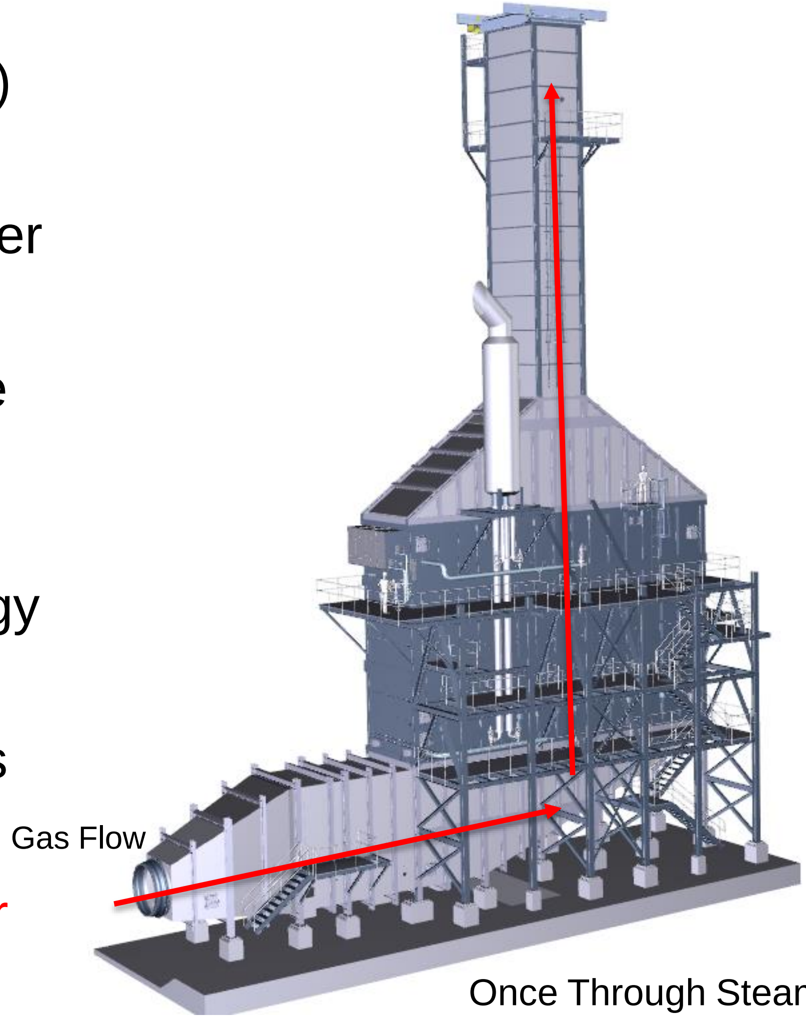
we find a better way

Once Through Steam Generator (OTSG)

Introduction to HRSGs

Heat Recovery Steam Generator (HRSG)

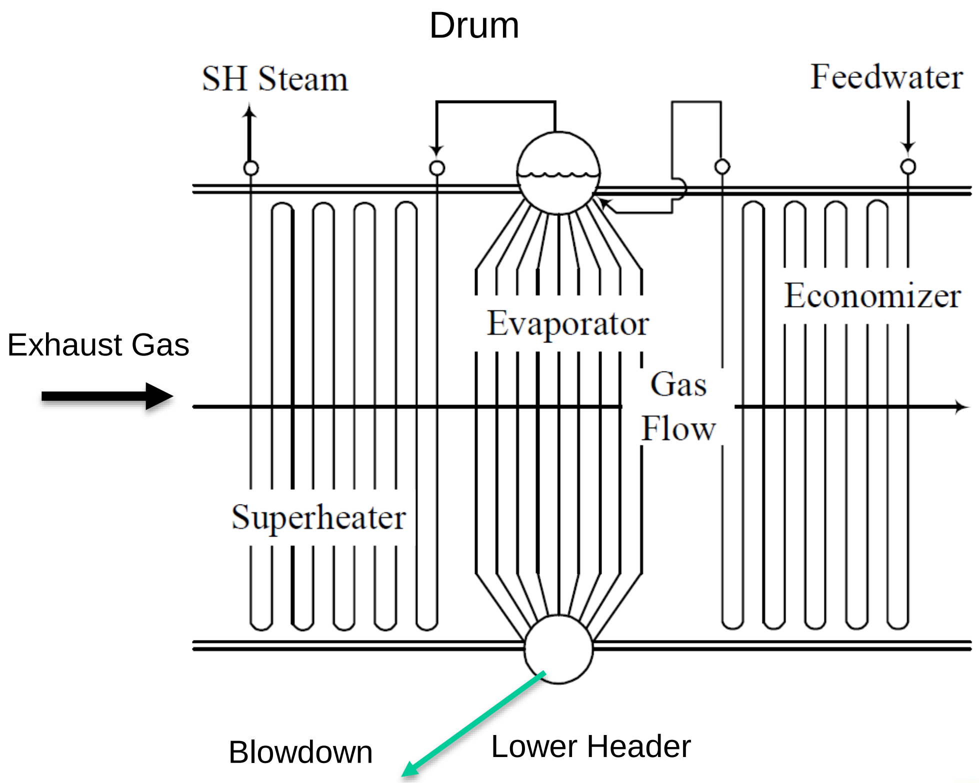
- Also referred to as a waste heat boiler
- Cools hot gas – most commonly the exhaust of a gas turbine
- Generates steam and regains energy
- Two main types of steam generators
    - Drum Boiler
    - Once Through Steam Generator (OTSG)



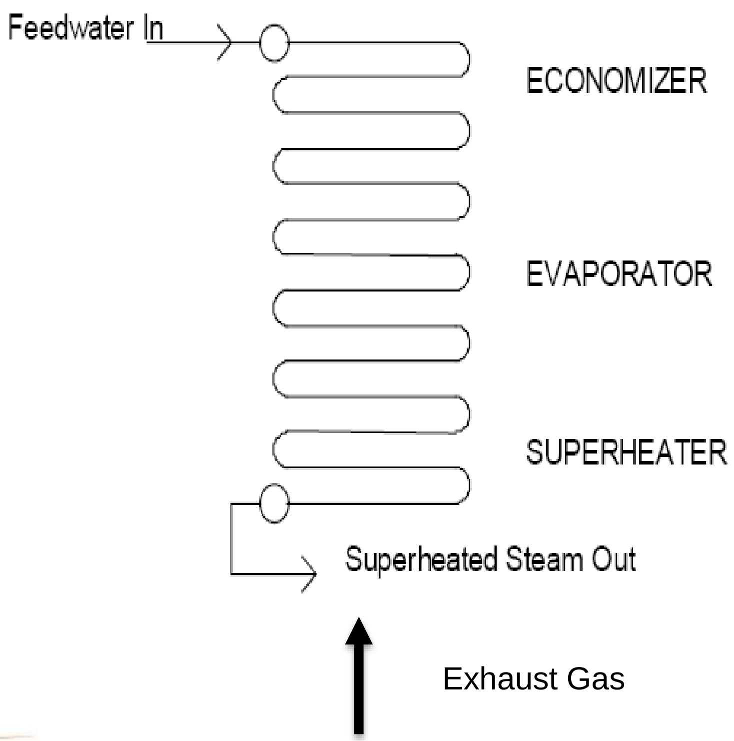
Once Through Steam Generator

Comparison: Drum Boiler and OTSG

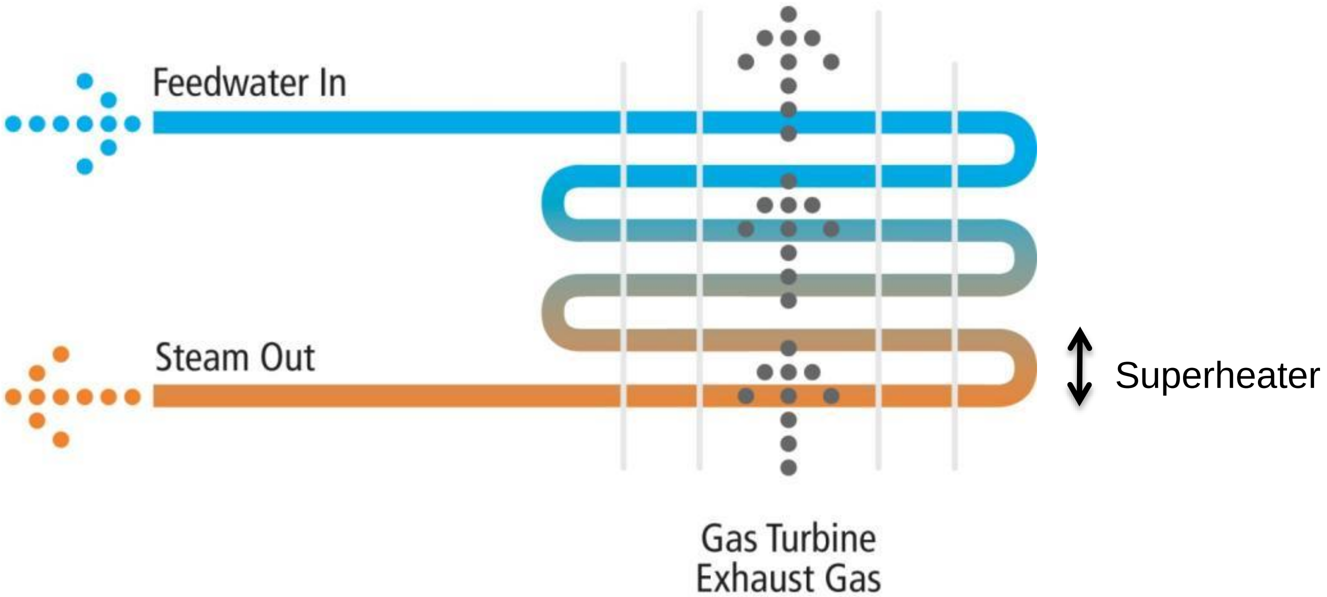
Drum-Type HRSG
Fixed Sections



OTSG Type HRSG
Non Fixed Section

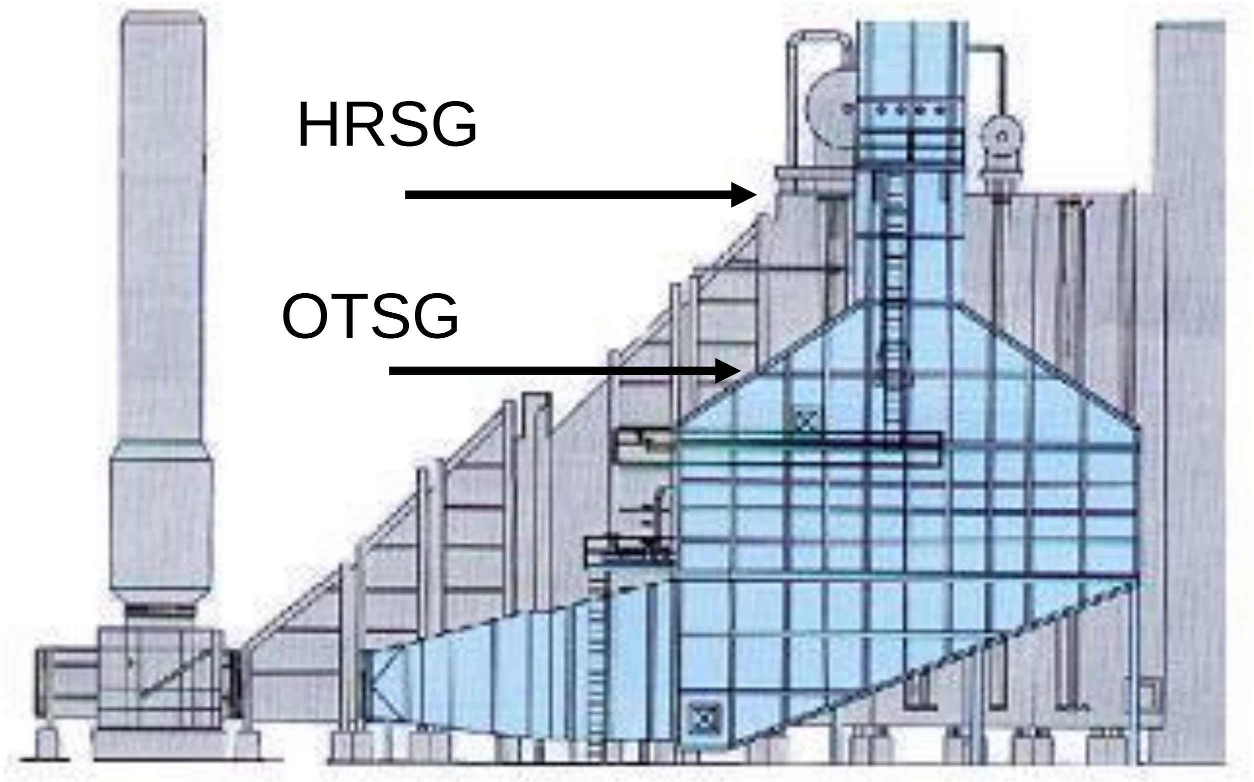


Once Through "Drumless" Design



- All tubes thin-walled → low thermal mass → fast cycling
- Compact lightweight pressure bundle
- Simple once through steam path (Water in = Water out)
- Zero Blowdown (no blowdown treatment)

OTSG vs Drum-Style HRSG



LM6000 Installation – overall size comparison

OTSG Pressure Bundle

Multiple parallel circuits
1” to 1.5” diameter
tubes

Compact shop installed
modules

Innovative Steam Technologies

we find a better way

Engineering Challenges to Meet Market Demands

OTSG Challenges – Market Demands

Steam generation needs to aligned to varying electrical load demands. OTSGs must be:

1) Capable of load following - Flexible steam rate operation to match required demand
2) Fast cold and hot starts
3) Augment steam production with duct firing
4) Emissions control (NOx and CO)

Load Following - Dry Running Capable

- Dry run gives advantages of flexible simple cycle operation with the efficiency of combined cycle operation

- "De-couples" combustion cycle from steam cycle
  - Gas turbine starts independently from the OTSG.

- Maintains gas turbine quick start capability
  - 10 minute simple cycle starts

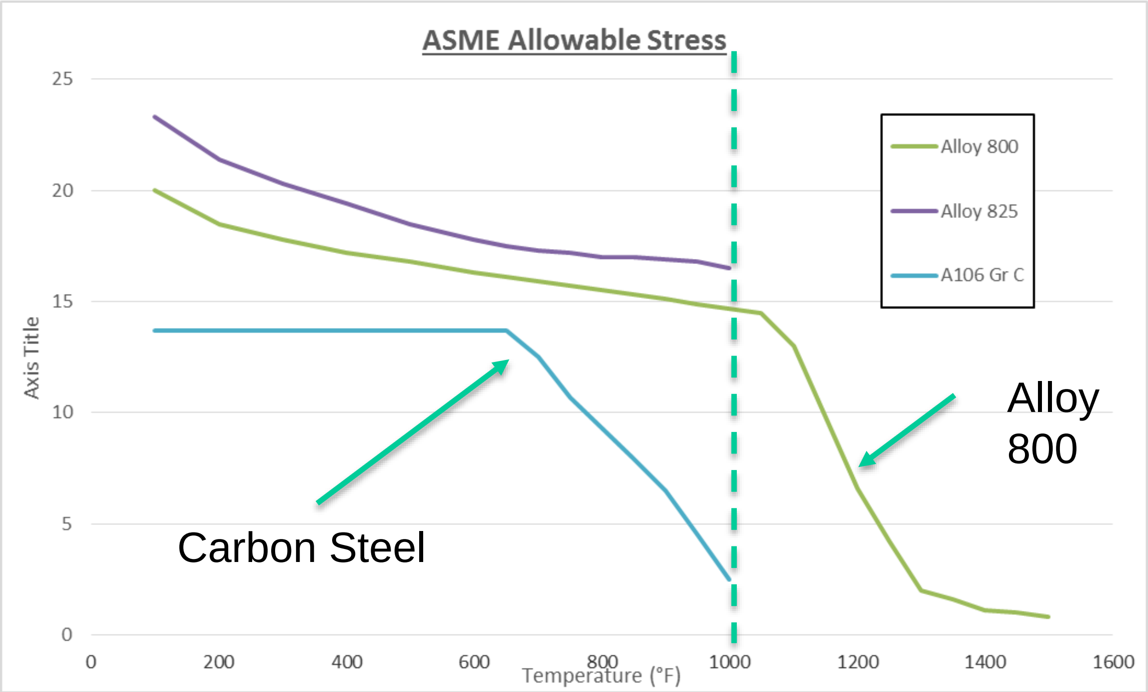
- Offers greatest operational flexibility with large flow rate range

Load Following - Dry Running Capable

- OTSG capable of dry operation is designed to withstand the full gas turbine temperature (up to 1170 F). Requires special tube materials and supports.

- Materials of choice: Alloy 800 and 825 (High Nickel – Chrome)
  Highly corrosion resistant and high strength

	Alloy 800	Alloy 825
Ni	30-35	38-46
Cr	19-23	19.5-23.5
Mo	------	2.5-3.5
Cu	------	1.5-3.0
Fe	39.5	22



Accommodates cold feedwater
60° F (17° C)

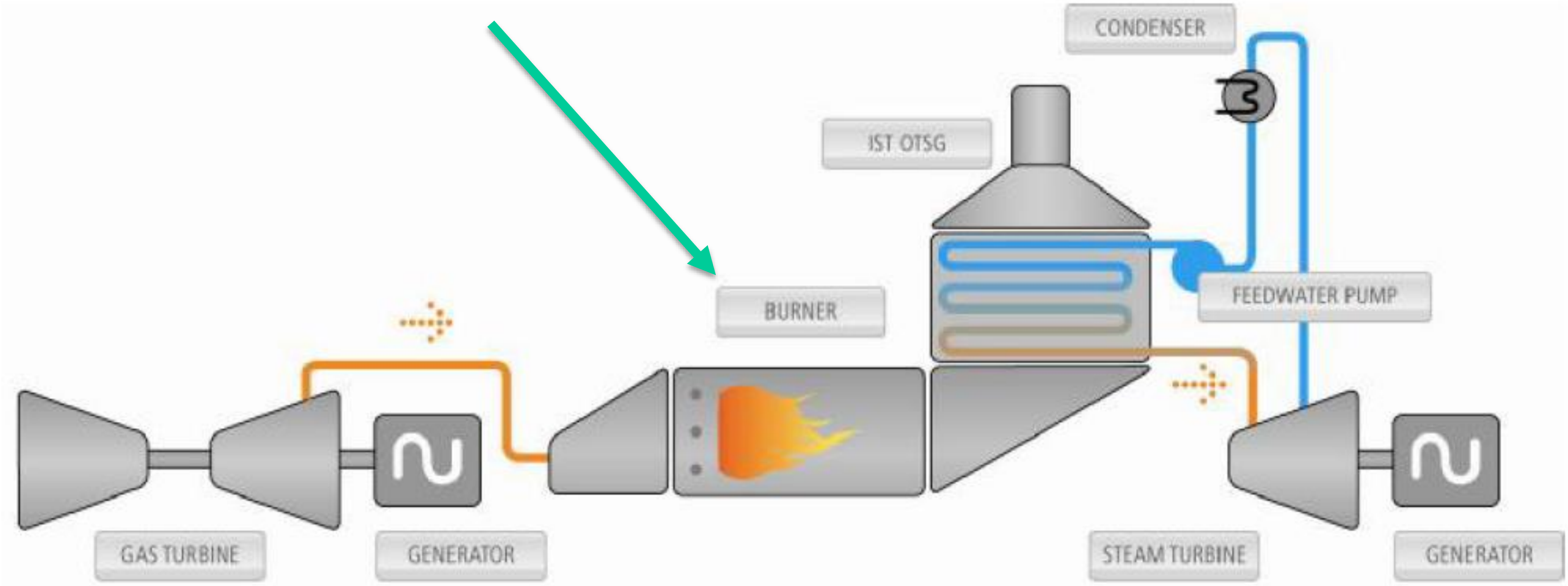
Load Following – FAST Start

- OTSG capable of rapid start to full load steam flow in under 15 minutes to meet grid electrical requirements
- OTSG are ideally suited for rapid start due to thin pressure tubes
- Drum boilers with thick wall steam drums requiring slow thermal ramp start.
  - Thermal fatigue is a major issue in drum boilers even with slow starts

Typical Steam Drum
(can be > 3" thick wall)

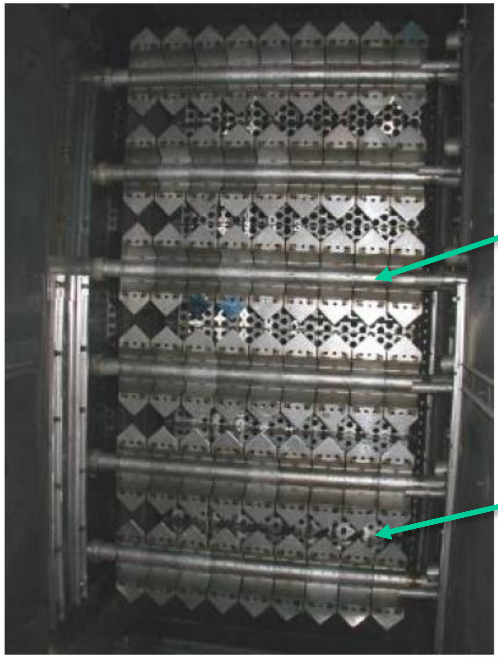
Steam Augmentation - Duct Burners

- Supplemental heat input to augment steam output and improve efficiency and meet system power demands
- Exhaust gas typically has enough oxygen (15% O2) to sustain stable combustion. Duct fired to temperature of 1200 to 1500 F.



Steam Augmentation – Why Duct Fire?

1. Steam demand increases without any change in the gas turbine exhaust
2. Insufficient heat available heat from the gas turbine to achieve steam flow
3. Gas turbine is completely down but steam is still needed using an auxiliary fan which replaces the GT flue gas flow (Fresh Air Firing).



Burner runners

Upstream flow distribution grid

Exterior gas manifold

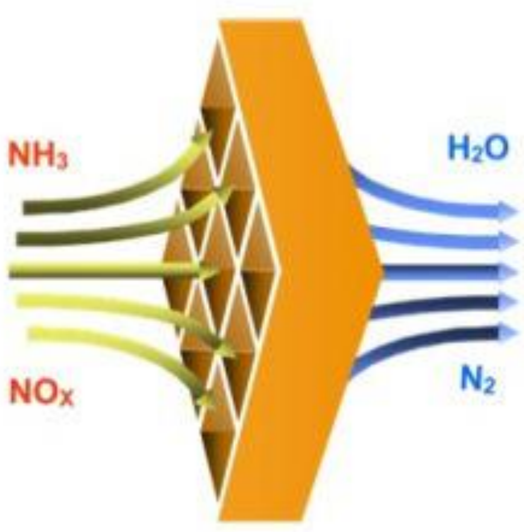
Flow Distribution Grids

- Grids are used to correct turbine exhaust gas flow mal-distribution
- Variable porosity plates and turning vanes are commonly used
- Typical gas side pressure drop for a variable porosity plate ranges from 0.5” H_2O to 3 inches H_2O
- Must meet stringent flow uniformity requirements by burner vendors

Emissions – NOx SCR Technology

A process in which ammonia (NH_3) is injected into the gas stream containing NOx upstream of the SCR catalyst.

The gas stream then passes through the catalyst layer decomposing NOx (nitrous oxides, principally NO and NO_2) into N_2 and H_2O.



Basic Reactions

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 4\,N_2 + 6\,H_2O$$

$$6\,NO_2 + 8\,NH_3 \rightarrow 7\,N_2 + 12\,H_2O$$

Undesired Parallel Reactions

$$SO_2 + 1/2\,O_2 \rightarrow SO_3$$

Forms sulfuric acid

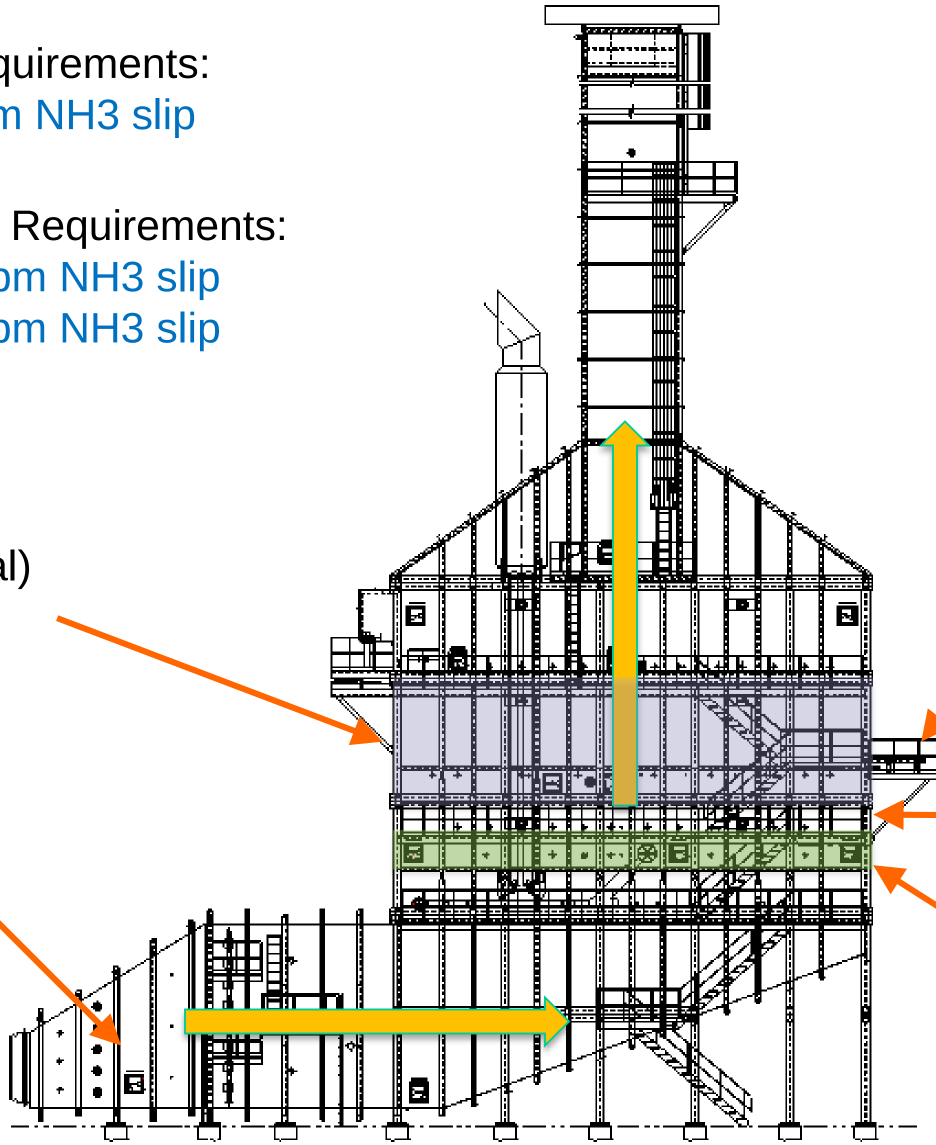
$$NH_3 + SO_3 + H_2O \rightarrow NH_4HSO_4$$

Ammonium Bisulfate

Typical Layout of OTSG w/ SCR & CO Catalysts

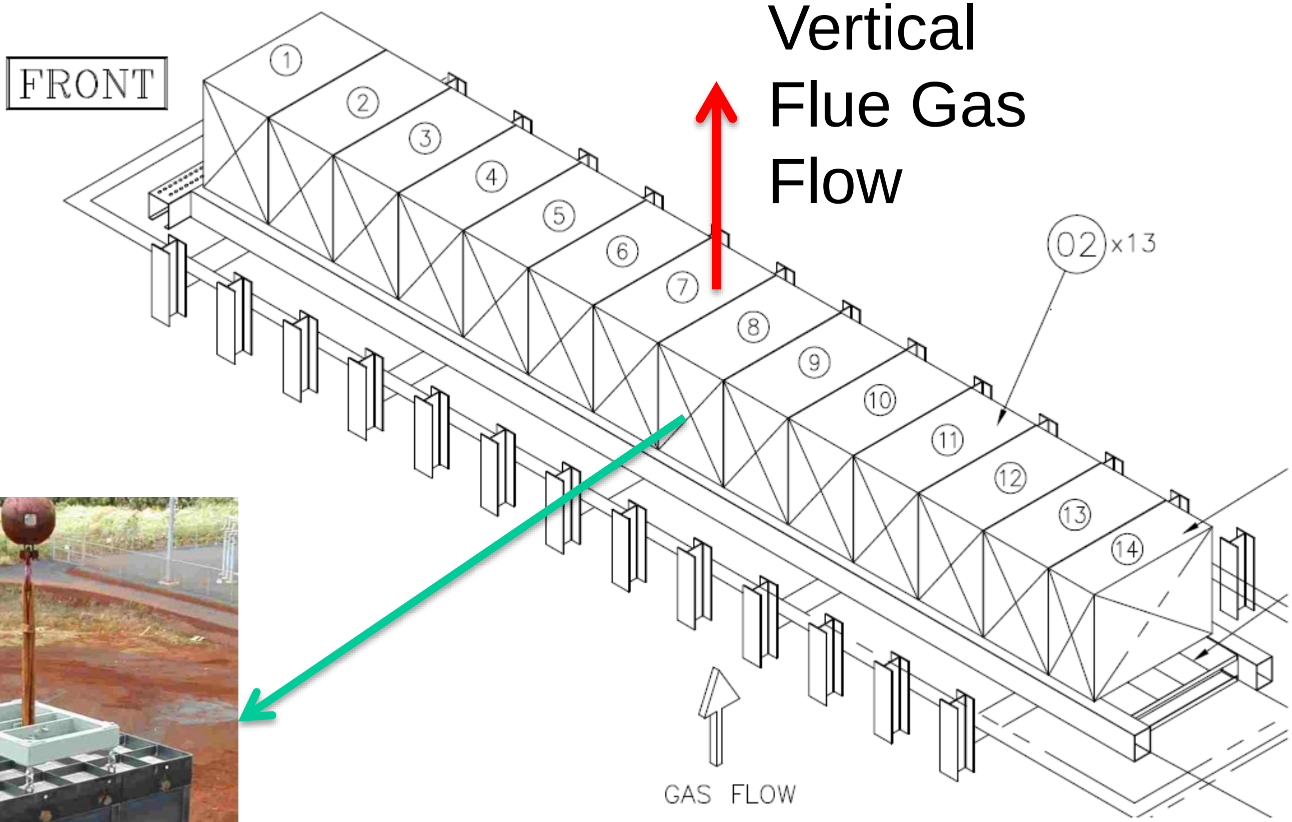
New Emission Requirements:
2 ppm NOx / 5 ppm NH3 slip

Previous emission Requirements:
2 ppm NOx / 10 ppm NH3 slip
5 ppm NOx / 10 ppm NH3 slip



SCR Catalyst

Vertical Flue Gas Flow

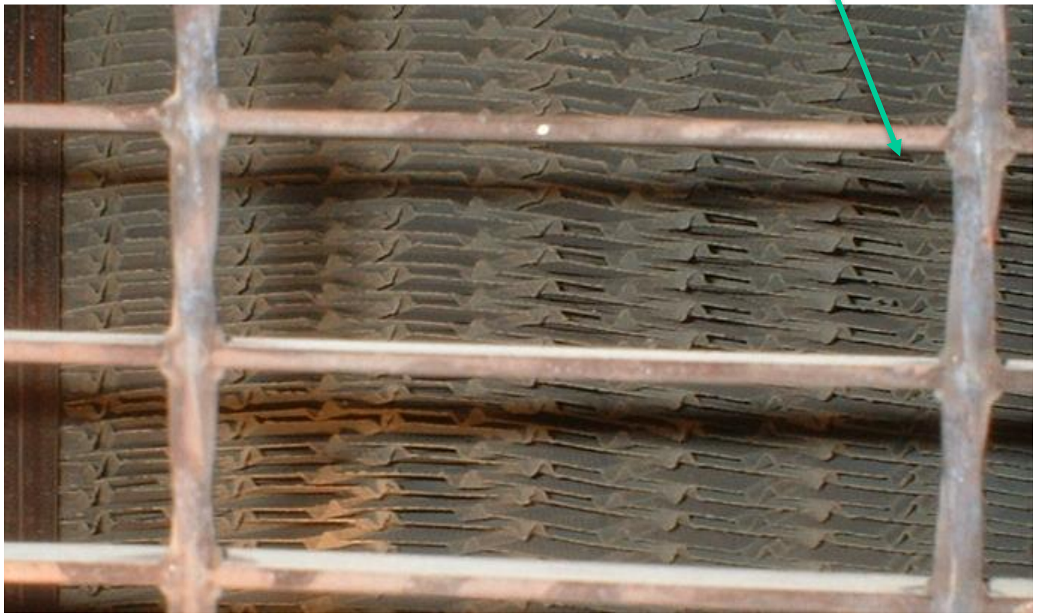


Cross Section Through SCR Module

Installed SCR Catalyst

- High temperature support frame
- Grating to allow for personnel walking on catalyst surface

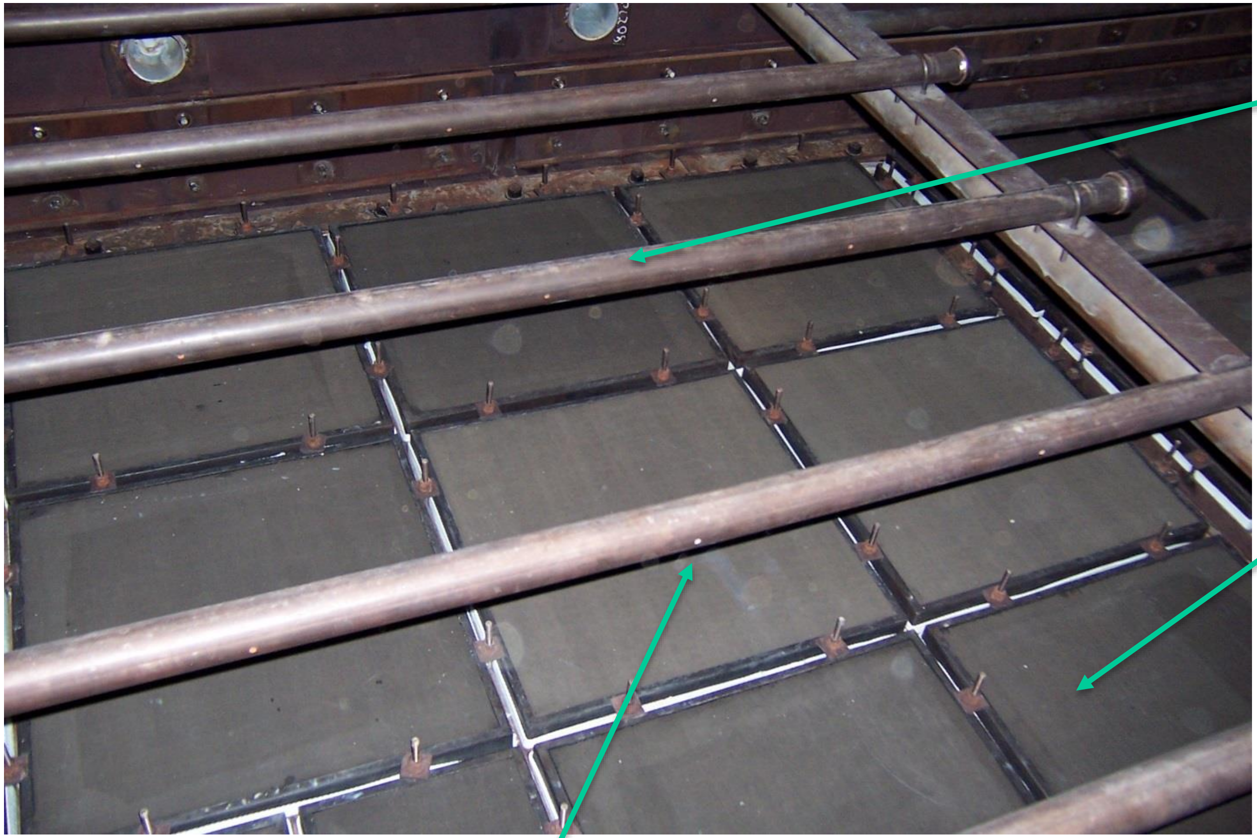
Downstream Side View



Upstream Side View

- Ti-O2-W catalyst blend on a stainless wire mesh
- Compact corrugated catalyst sheets stacked side by side
- Located in tube bundle at optimal temperature 700-750F

Ammonia Injection Grid (AIG)



Injection pipes (1.5” to 3” NPS) with drilled holes

Upstream CO catalyst (Platinum)

Ammonia injection holes

Innovative Steam Technologies

we find a better way

Engineering Tools

Engineering Tools

Computer simulations play an important role in the OTSG design.

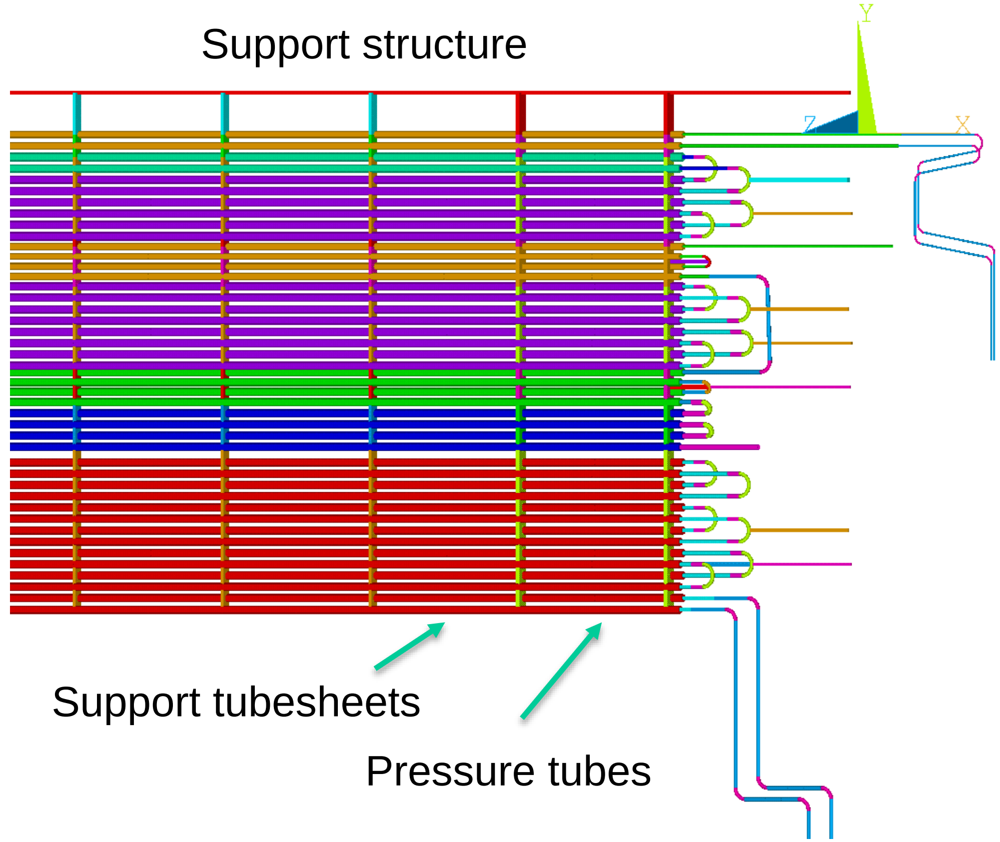
Finite Element Analysis (FEA) – Calculation of pressure part and structural member stresses, deflection, loads

Computational Fluid Dynamics (CFD) – Calculations of flow velocities, temperature, concentrations

FEA- Loads / Stresses / Deflections

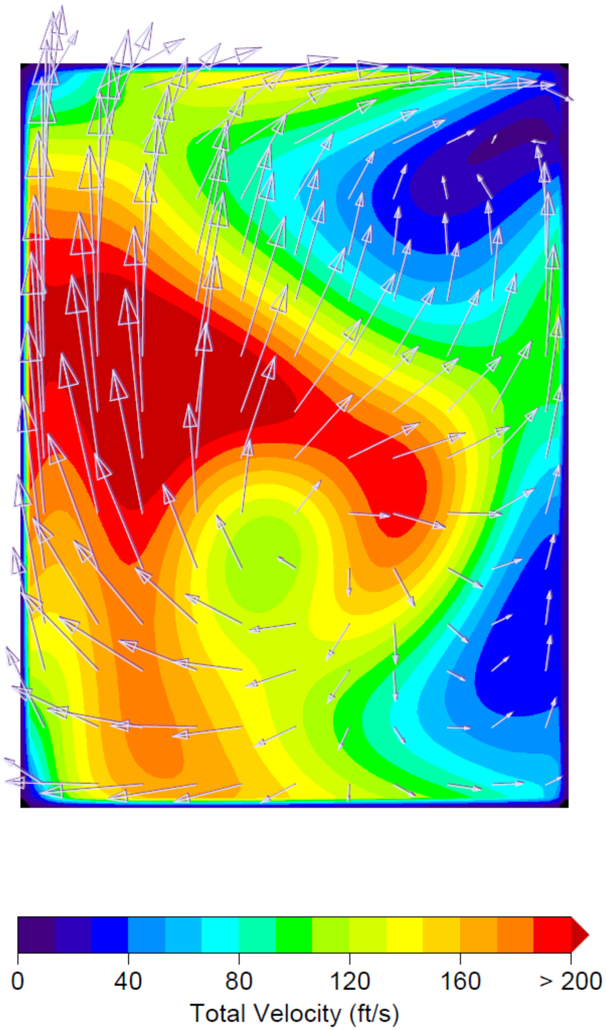
Finite Element Analysis is an important tool used to understand:

1. Thermal expansion of tubes and supports
2. Operating stresses and design margins
3. Support and restraint loads



- ANSYS FEA software
- Tube row by row gas and metal temperatures are imported for accurate representation

CFD - Turbine Exhaust Profile



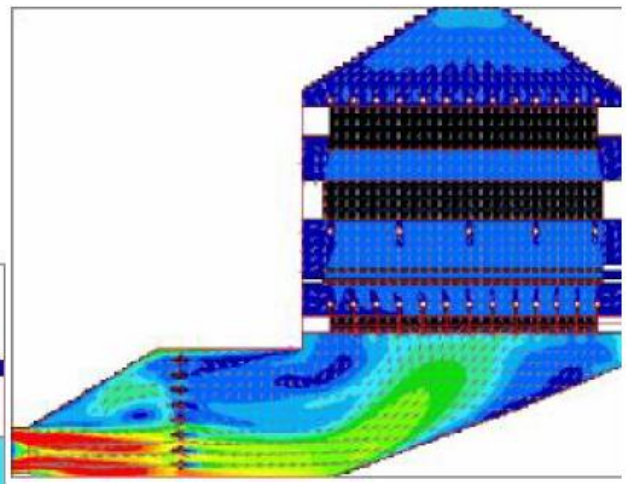
- Turbine exhaust is highly non-uniform flow and temperature profile.
- The flow vectors often include a swirl characteristic
- Flow velocity contour plots can range over wide range

What does this mean?

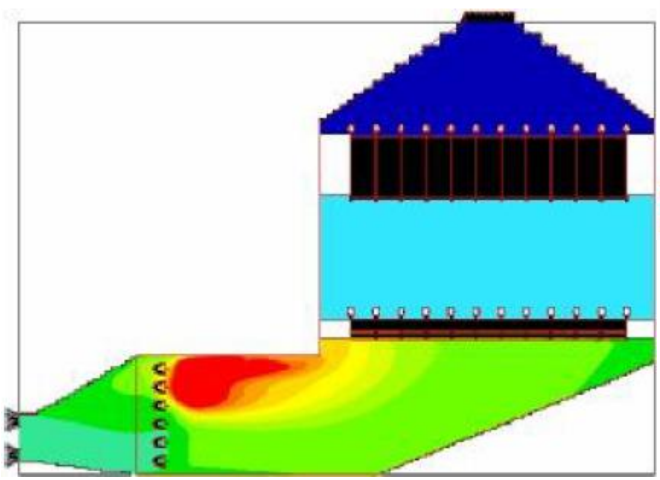
Flow distribution devices are a necessity to smooth out flow into the OTSG

Flow Modelling – Horizontal Flow Arrangement

- Gas flow distribution leaving the gas turbine is non-uniform
- Proper performance of the HRSG, duct burner and emission equipment requires uniform flow and temperature profile

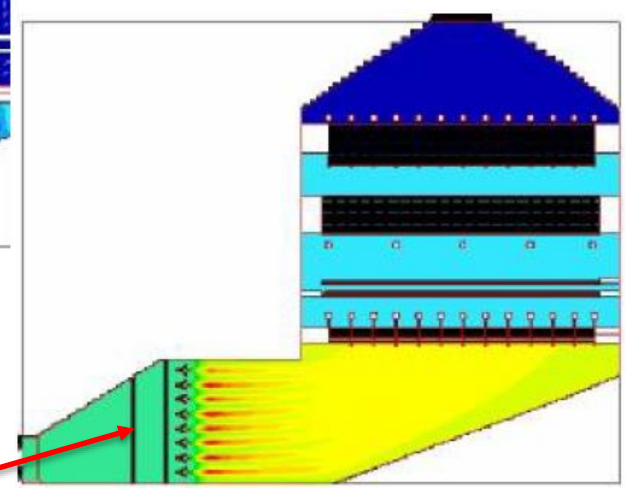


Initial Flow Velocity



Initial Temperature

2 Flow Distribution Grids



Final Temperature

Combustion Modelling – Flame

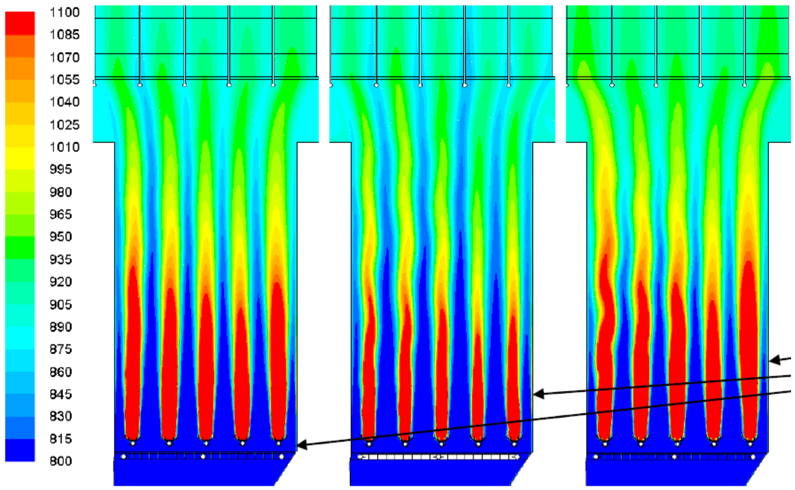


Figure 42: Temperature distribution in the range 800 to 1100 [K].

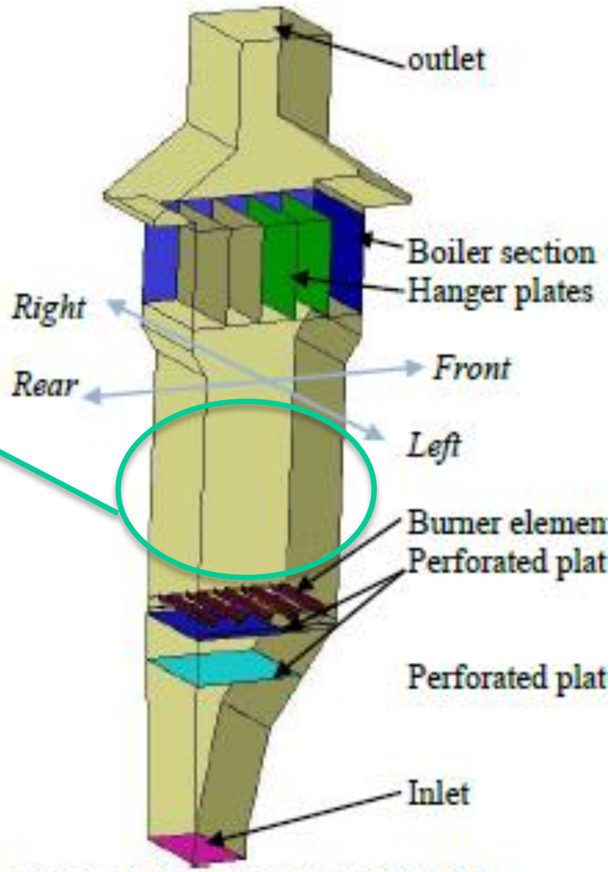
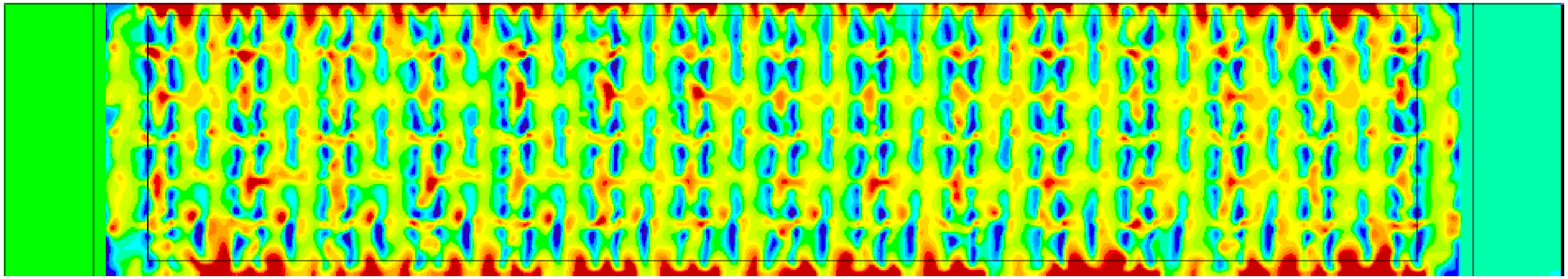


Figure 1 Shaded outline of model

CFD combustion modelling allows for accurate determination radiant and temperature distribution

CFD– SCR Ammonia Modelling

- Confirm AIG hole pattern creates a uniform ammonia distribution from each lance pipe
- Dispersion CFD modelling to ensure ammonia injected by AIG piping is uniform at SCR inlet face
- Important to meet uniform NH3 / NOx distribution



Ammonia mass distribution upstream of SCR before optimization

Innovative Steam Technologies

we find a better way

Innovation – Key to Develop New Markets

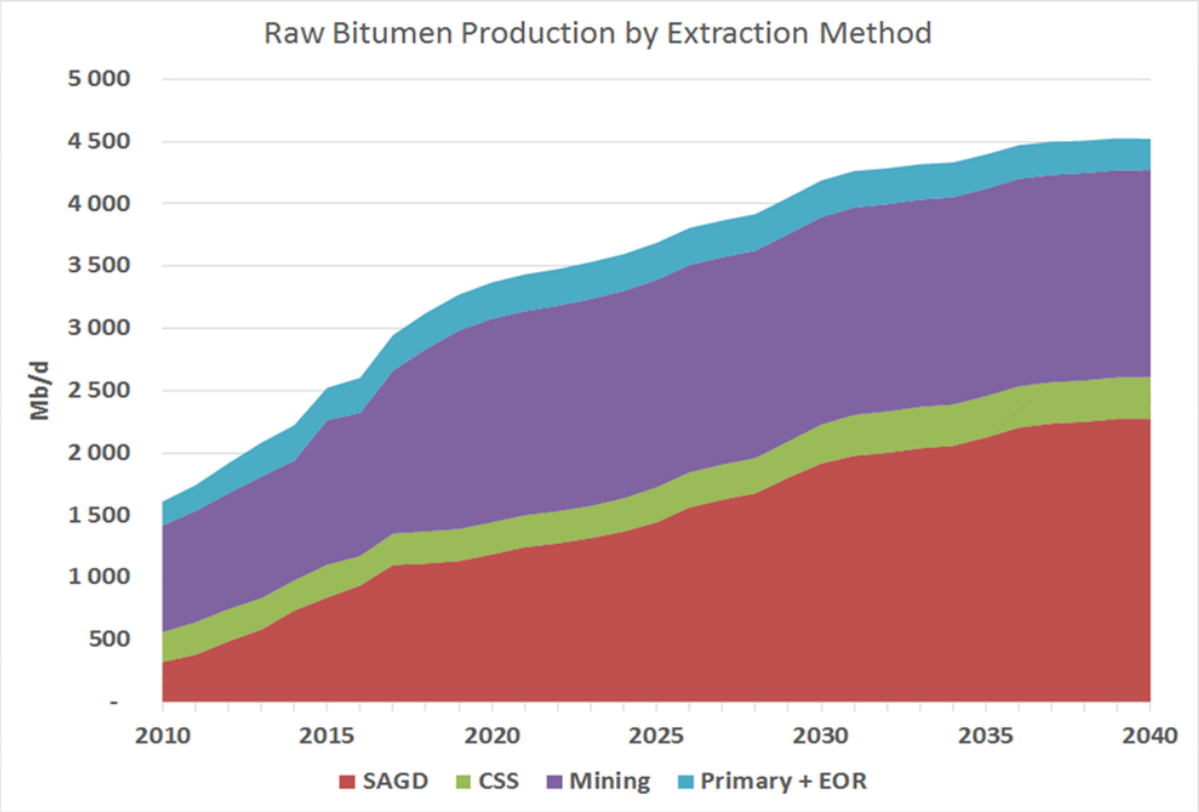
Innovative Steam Technologies

we find a better way

Innovation

Enhanced Oil Recovery OTSG

Current Climate – NEB (National Energy Board)

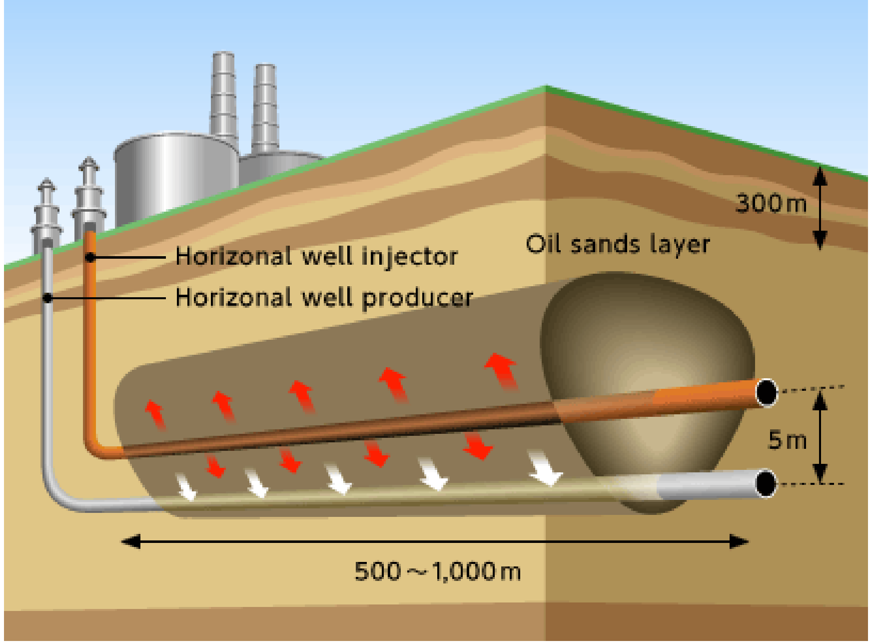


National Energy Board recently released Canada's Energy Future 2017 Supplement

- Remaining 80% of oil sands only accessible using in-situ methods
- Steam injection is the primary proven method to recover oil/bitumen

Enhanced Oil Recovery (EOR)

ALBERTA : Steam Assisted Gravity Drainage (SAGD)



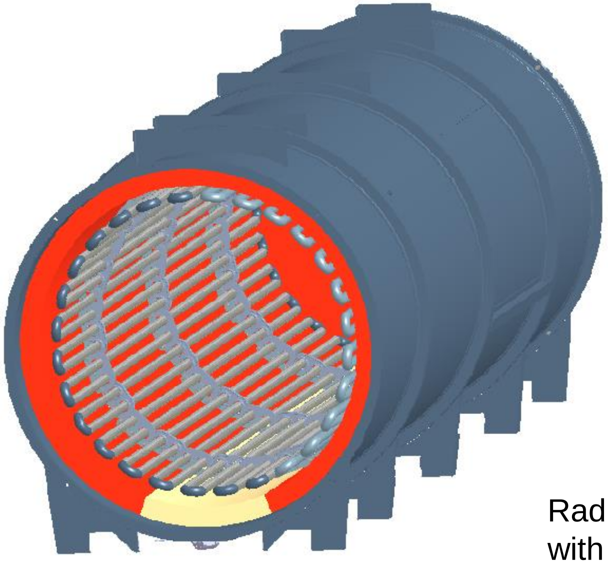
OTSGs provides the majority of steam for EOR worldwide!

EOR OTSG

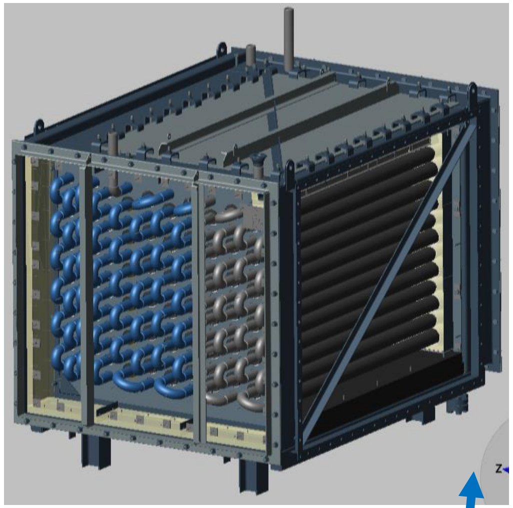
Petrofac/ Lower FARS

60,000 Barrels Oil / Day

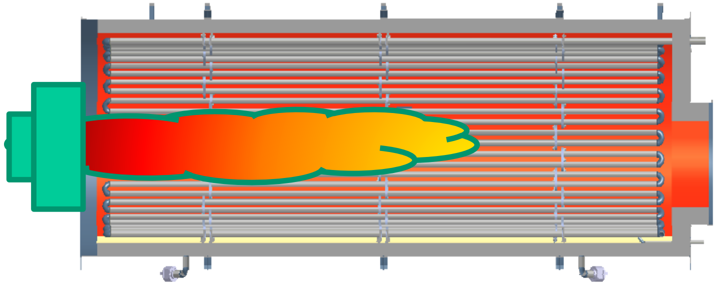
Fired OTSG Design



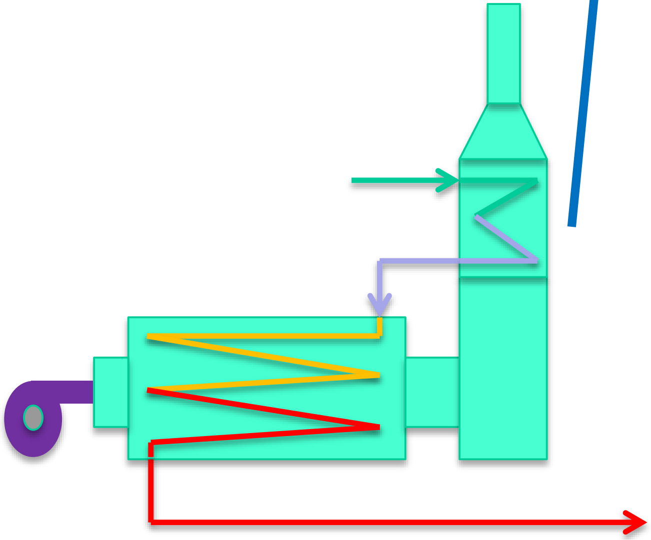
Radiant Chamber
with Pipes



Convective Heat
Transfer Module



Combustion Chamber



OTSG Inlet Water Quality

Extremely high Total Dissolved Solids (TDS) is unique to EOR OTSGs

Boiler Feedwater

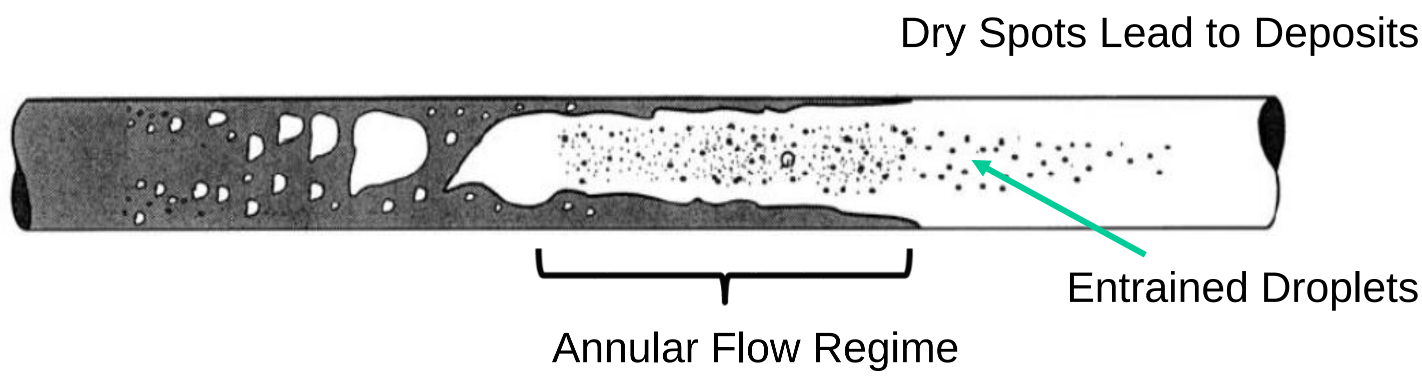
Steam Blowdown Water

Constituent	Unit	Maximum Limit
Total Silica	ppm	50
Total Iron	ppm	0.05
Hydrogen Sulfide	ppm	0
Total Acidified Hardness (as $CaCO_3$) - Normal (Excursion)	ppm	0.2 (0.5)
Total Alkalinity	ppm	<2000
Total Dissolved Solids	ppm	<8000
Total Organic Carbon	ppm	------
Total Suspended Solids	ppm	1
Oil & Grease	ppm	0.5
Turbidity	NTU	2
pH	pH	>9.3
Oxygen	ppb	5

OTSG must produce wet steam to carry through BFW dissolved solids!

Industry Standard

- OTSG radiant piping outlet operates under **annular** flow regime



- A **layer of water** on the pipe surface absorbs incoming radiant energy (steam core with droplets)
- Water **impurities are carried through** in steam water content.
- KEY – to maintain water contact on the pipe surface
- Industry standard – Operate **75 to 80**% steam quality based on proven reliable experience

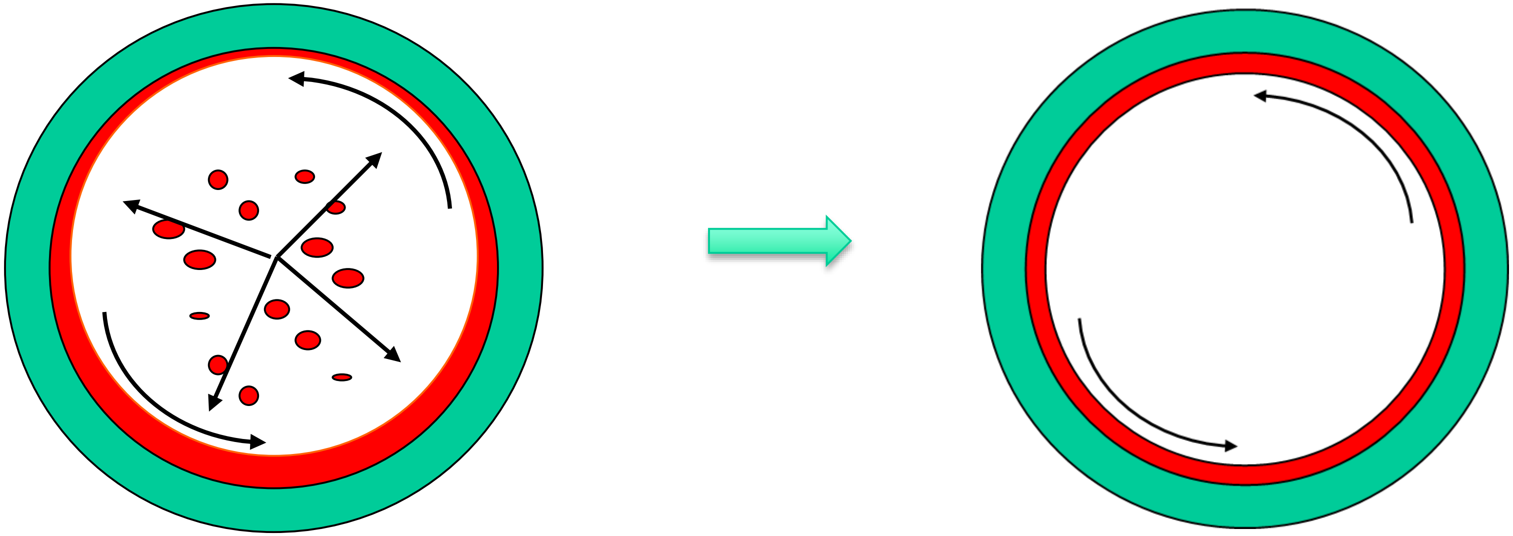
IST SQ90^{TM} Solution to Higher Steam Quality

- Internally Rifled Pipes:
  - Maintains all water on pipe surface and equalize water impurity concentrations
- The internal surface has a series of **raised ribs** that imparts a **rotational fluid flow**
- The **centrifugal** force pushes all entrained water **equally** around pipe perimeter
- Operates at **90% steam quality (an industry first !)**

Inside Rifled Pipe

The SQ90^{TM} OTSG design is **patented in Canada, US and GCC (pending)**

IST SQ90™ Solution to Higher Steam Quality



Uniform Surface Water Film = Ability for High Steam Quality

Innovative Steam Technologies

we find a better way

Innovation

Organic Rankine Cycle OTSG

Organic Rankine Cycle (ORC)

- Many small gas turbines and generators are run in simple cycle
  - An opportunity exists for improved system efficiency
  - However, at existing sites there is rarely a local use for the heat

- US Department of Energy estimates there are **1.5 to 2.0 quadrillion BTU/hr** with gas temperature < 500 F from industrial gas streams. A HUGE potential for carbon reduction!

- Smaller gas turbines have insufficient heat available for heat recovery using steam making the system inefficient.
  - Switch to **organic fluids (ie. R245fa)** for heat recovery and electricity generation (Referred to Organic Rankine Cycle (ORC) process)

- ORC application: Gas temperature less than **800 F (427 C)**

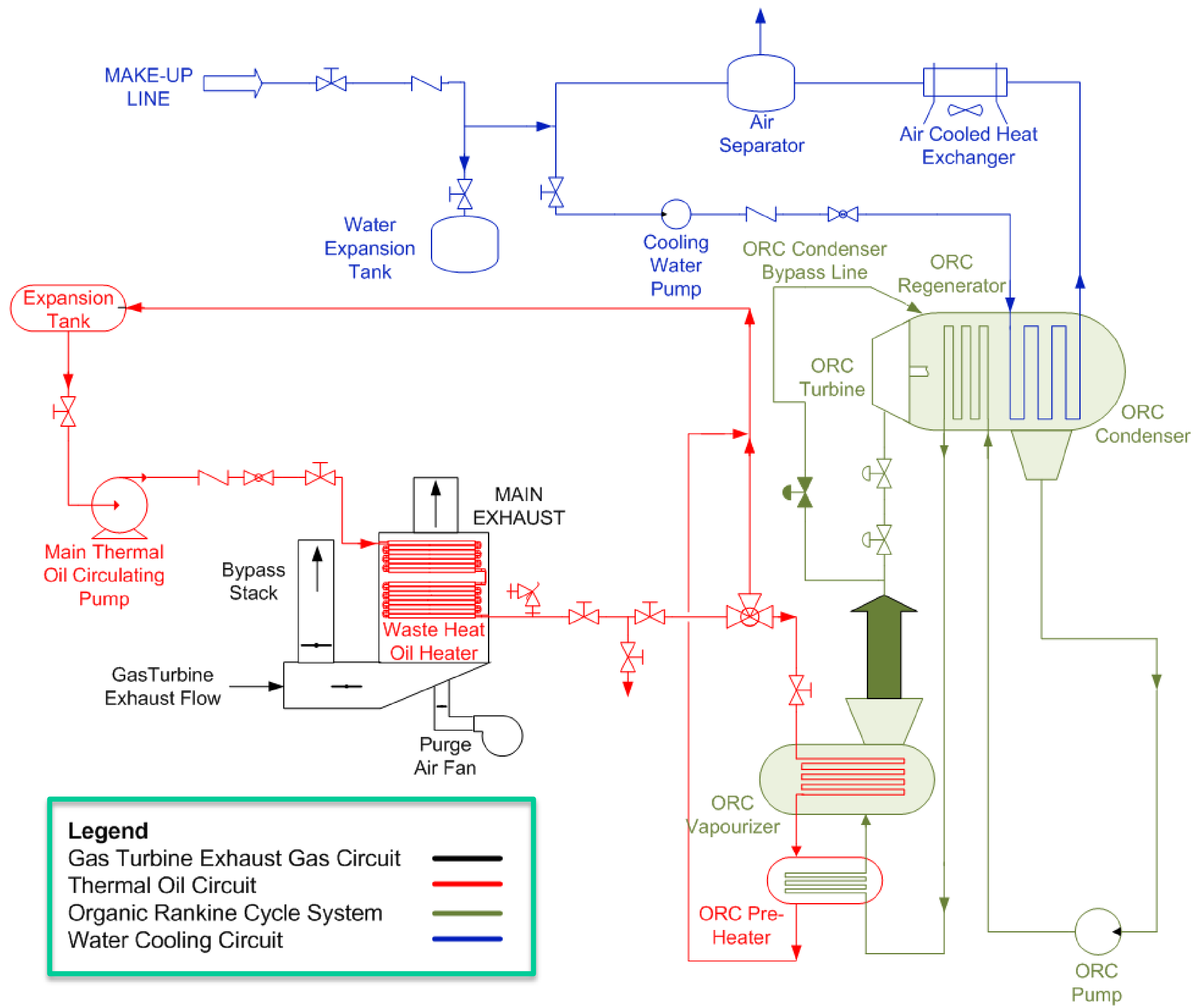
TransGas Rosetown Project Example

- Natural gas compressor station in southwestern Saskatchewan
- Compressor driven by Solar Centaur Gas Turbine (4500 HP)

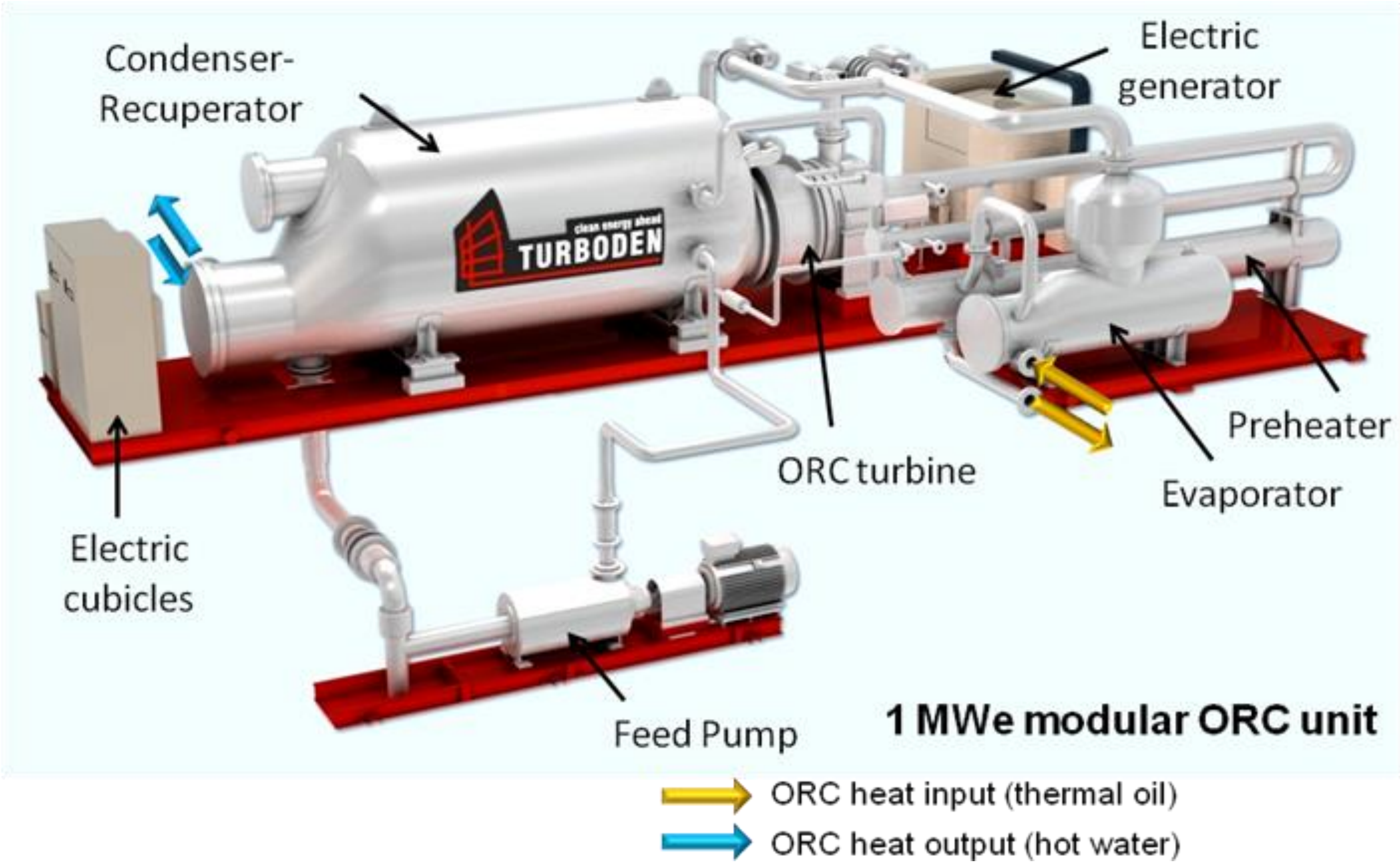
Turboden: ORC turbine / regenerator / generator

- IST supplied an EPC turnkey 1MWe power plant utilizing waste heat from the Solar Centaur GT (800 F flue gas temperature)

ORC - Process Flow Diagram

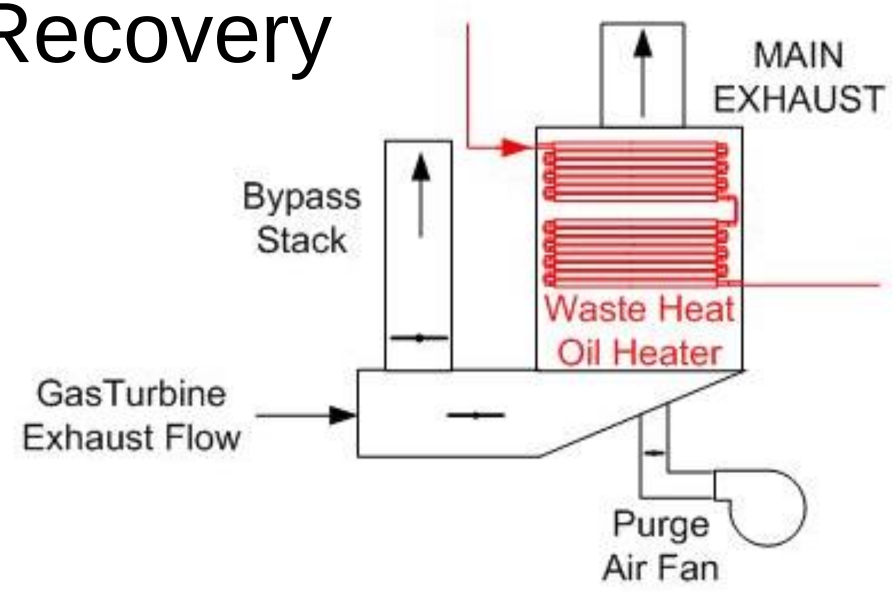


ORC Plant Layout



Provided by Turboden

OTSG – Flue Gas Heat Recovery



Waste heat oil heater (OTSG)

By-pass stack

Turbine exhaust

ORC Advantages

- Organic working fluid has low boiling point (Efficient).
- Fully automated plants
- Low system operating pressure (Safe)
- High molecular weight working fluid
  - Low speed turbines that increase the system reliability and efficiency.
- 'Dry fluids': Vapour always leaves the turbine in a superheated condition.
  - No risk of damaging turbine with liquid.

ORC Challenges

- High installed costs often makes projects prohibitive. Must have installed costs <$5000/kWe
- Feasible only for regulated electricity markets with high electrical sell costs (> $0.16 /kW-hr)
- Expensive organic fluid replacement costs
- Most economical solutions begin at 1MWe and higher. Leaves behind a large untapped market.

ORC Innovation Next Steps….

- Direct evaporation of organic working fluid in the turbine or reciprocating engine flue gas.
  - Challenge: Overheating H245fa can form hydrofluoric acid

- Eliminate thermal oil transfer loop reduces cost and increases overall efficiency

- Completely modular design to minimize field erection costs

- Turbo expander cost reduction

Innovative Steam Technologies

we find a better way

Future Challenges

Canada Future Challenges

- Electrical producers maintaining competitiveness in a carbon tax environment
  - Development of low cost CAPEX and OPEX CO2 capture technology
- Suppressed oil prices and carbon tax making Canada's oil sands industry unprofitable
  - Lack of investment in today's market
- Reduced NOx emissions
  - Challenges to achieving sub 2 ppm NOx
- Development of more cost effective Organic Rankine Cycle heat recovery
  - CAPEX costs need to be driven down

Innovative Steam Technologies

End

Questions?

once
through
steam
generators