PRINCIPLES OF ENERGY CONVERSION
TO IMPROVE AND SUSTAIN THE QUALITY OF LIFE AROUND THE WORLD

JOHN MCCONNACHIE
MECHANICAL ENGINEER, ENERGY BUSINESS
AGENDA

- Who Is Black & Veatch?
- Energy Group, Ann Arbor
- Overview of Traditional Thermal Cycles
- Overview of Combined Cycles
- Major Equipment of Combined Cycles
- Design Options for Combined Cycles
- Air Quality Control for Combined Cycles
- Review of Latest CTG in CC Technology Options
- Renewables
- New Hire Responsibilities
- Questions
WHO IS BLACK & VEATCH?
WE’RE BUILDING A WORLD OF DIFFERENCE. TOGETHER.

• Founded in 1915
• Global workforce of more than 10,000
• Employee-owned corporation
• $3.6 billion in annual revenues in 2013
• More than 110 offices worldwide
• Completed projects in more than 100 countries

Black & Veatch conducts 7,000+ active projects globally at any one time
OUR EMPLOYEE-OWNED COMPANY IS GUIDED BY OUR VISION, MISSION AND VALUES

VISION
Leading our Industry in Value Creation

MISSION
Building a World of Difference

VALUES
• Integrity
• Shared Ownership
• Common Purpose
• Stewardship

• Respect
• Accountability
• Entrepreneurship
WE LIVE BY THE BLACK & VEATCH CODE OF CONDUCT NO MATTER WHERE WE OPERATE

PROMOTES OUR VALUES AND OUTLINES CONDUCT DISCOURAGED OR PROHIBITED

Laws, Customs and Practices
External Operations
Internal Operations
Individual Responsibilities

All professionals are required to report any known or suspected violations to confidential, toll-free number
BLACK & VEATCH HAS REGIONAL OFFICES THROUGHOUT THE UNITED STATES

Arizona
California
Colorado
Delaware
District of Columbia
Florida
Georgia
Illinois
Indiana
Kansas
Kentucky
Louisiana
Maryland
Massachusetts
Michigan
Minnesota
Missouri
Nebraska
Nevada
New Jersey
New York
North Carolina
Ohio
Oregon
Pennsylvania
South Carolina
Texas
Virginia
Washington

Project offices are not included.
OUR GLOBAL PRESENCE ALLOWS US TO APPLY GLOBAL EXPERTISE LOCALLY

Afghanistan
Armenia
Australia
Azerbaijan
Bahrain
Canada
Chile
China
Czech Republic

Georgia
Hong Kong
India
Indonesia
Kuwait
Kazakhstan
Malaysia
Mexico
Netherlands

Oman
Palestine
Philippines
Puerto Rico
Russia
Saudi Arabia
Singapore
South Africa

Taiwan
Thailand
Turkey
Ukraine
United Arab Emirates (UAE)
United Kingdom
United States
Vietnam
SOLVING THE WORLD’S COMPLEX CHALLENGES IN EACH OF OUR MARKETS

Energy
Indonesia

Water
Hong Kong SAR

Telecommunications
California, USA

Security
Armenia

Management Consulting
Oklahoma, USA

Environmental
Scotland, UK

Using teamwork and collaboration we provide sustainable and reliable solutions
THE RESULT IS A POSITION OF INDUSTRY LEADERSHIP

1st – Top 20 in Telecommunications
1st – Top 25 in Fossil Fuel
3rd – Top 20 in Power
3rd – Top 20 in Transmission Lines and Aqueducts
4th – Top 25 in Transmission and Distribution Plants
4th – Top 20 Contractors in Telecom
5th – Top 10 in Hydroplants
5th – Top 20 in Nuclear Plants
5th – Top 15 in Dams and Reservoirs
6th – Top 25 in Wastewater Treatment Plants
6th – Top 25 in Sanitary and Storm Sewers
6th – Top 20 in Water
8th – Top 20 in Sewerage and Solid Waste
9th – Top 20 Contractors in Power
10th – Top 20 in Water Treatment, Desalination Plants
11th – Top 50 Contractors Working Abroad
12th – Top 25 in Refineries and Petrochemical Plants
16th – Top 500 Design Firms

2nd – Top 100 Federal Contractors
Architectural & Engineering Services
We have extensive construction experience on projects of complex size and scope throughout the world.

Black & Veatch Construction, Inc. (BVCI) for union construction

Overland Contracting Inc. (OCI) for open shop construction

Black & Veatch International (BVI) for work outside the U.S.
WE UNDERSTAND THE ENTIRE LIFE CYCLE OF A POWER PLANT
ENERGY GROUP
ANN ARBOR, MICHIGAN
ANN ARBOR OFFICE OVERVIEW

- Michigan Business Began in 1980
- Ann Arbor Office Opened in 1988
- Expanded Scope
- Power Generation Services
- Renewables & Energy Efficiency
- Power Delivery
- Facilities
ANN ARBOR OFFICE STAFF

• 278 Total Energy Division Home Office Professionals
  • Procurement
  • Quality
  • Project Controls
  • Marketing
  • Accounting
  • Administrative/Support
  • Project Management
  • Civil/Structural/Architecture
  • Mechanical/Chemical
  • Electrical/Controls
  • Power Delivery
  • Construction

• Engineers registered (PE) in 31 states and 14 individual professionals registered in Canada

• All network frequently with specialists in our headquarters office

• Our staff has experience working on all facets of the power industry, including OE, EPC, EPCM
STAFF BREAKDOWN IN ANN ARBOR

TOTAL FULL-TIME STAFF = 278

- Architecture
- Chemical Engineering
- Civil Engineering
- Construction Management
- Economics
- Electrical Engineering
- Power Delivery
- Geological Engineering
- Information Technology
- Mechanical Engineering
- Procurement
- Project Controls
  - Scheduling
  - Cost Estimating
- Project Management
- Renewables Energy & Efficiency
- Soil Mechanics
- Structural Engineering
ANN ARBOR OFFICE
AREAS OF EXPERTISE

- Combustion Turbine Facilities (SC & CC)
- Cogeneration Facilities
- Fossil Fueled Power Plants (Pulverized Coal and Fluidized Bed Combustion)
- New Generation Studies
- Multi-pollutant Studies
- NOx Compliance Projects
  - NOx Compliance Studies
  - SCR
  - SNCR
  - Low NOx Burners
- Fuels Conversions
- Ash Pond Design
- Substation Design
- University Powerhouse New Generation and Upgrades
- Coal Handling Systems
- Control System Replacements
- Repowering Studies
- Powerhouse Life Extension Studies
- Industrial Utilities Retrofit
- Performance Monitoring
- Construction Management
- Construction – Direct Hire
- Air Quality Control Systems
ENMAX/Capital Power
Shepard Energy Center
Calgary, Alberta
2009 PROJECTS OF THE YEAR
POWER ENGINEERING MAGAZINE

Pacific Gas & Electric’s Gateway Generating Station was selected as the best natural gas-fired project of 2009

Dallman Unit 4 was selected as the best coal-fired project of 2009 by editors of Power Engineering magazine
FOSSIL FUELED GENERATION
TYPES OF POWER PLANTS

• Simple Cycle Combustion Turbine (Brayton Cycle)
• Coal Fired Thermal Plant (Rankine Cycle)
• Combined Cycle Plant (Brayton/Rankine)
• Cogeneration Plant
RANKINE THERMAL CYCLE

• Rankine Cycle – a closed loop, vapor power cycle that forms the thermodynamic basis for most vapor (typically steam) power plants.

• The Rankine cycle is constantly evaporating and condensing the working fluid (typically water).
RANKINE THERMAL CYCLE

• Reheating takes place between points 4 and 5
• Points 4s and 6s show ideal isentropic expansion of the steam
RANKINE THERMAL CYCLE
HEAT REJECTION (ONCE THRU)

95F

To River or Other Heat Sink
Once Thru = No CT

From River or Other Heat Sink

70F

95F

90F
RANKINE THERMAL CYCLE
HEAT REJECTION (DRY)

ACC Inlet Air Temp.
Approach to ST Exhaust Temp.

ACC Exhaust Conditions
98.05 T
41.93% RH

Cycle Makeup

ACC Inlet Conditions
86F
61% RH

Air Cooled Condenser (ACC)
TRADITIONAL COAL FIRED POWER PLANT
(LOW SULFUR COAL BASIS)
CWLP DALLMAN UNIT 4

- Unit 4 – 200 MW Net with Pulverized Coal Boiler
- Commercial Operation Fall 2009
BRAYTON THERMAL CYCLE

• Brayton Cycle – an all gas power cycle where the working fluid is continuously compressed, heated, and expanded throughout the cycle. Typically the working fluid is air and combustion gas. It is an open cycle.
BRAYTON THERMAL CYCLE
SIMPLE CYCLE (GAS TURBINE ONLY)

- Waste heat (or low energy heat) is rejected to the atmosphere as shown diagrammatically by points 4 to 1.
- Notice that a heat exchanger is not required, saving significant capital dollars.
BRAYTON THERMAL CYCLE
SIMPLE CYCLE (GAS TURBINE ONLY)

Gas Turbine (GT) or Combustion Turbine (CT)

Ambient Air Conditions
14.48 p
57 T
60 %RH
3524 m

Inlet Air Filter

Evaporative Cooler
Water Flow Rate
↓ 5.413 m

Evap. Cooler

GT Inlet Conditions
14.29 p
50 T
3529 m

Air Compressor

OEM Name & Model of GT
1X GE 7241FA

Fuel Combustor

Fuel Type & Flow Rate
CH4 75.3 m
LHV 1620351 kBTU/h

Fuel Heat Input

Fuel Temperature Before Combustion
77 T

Exhaust Gas Flow Rate

Exhaust Gas Conditions
3605 m
CTG Gross Output
173597 kW
14.68 p
1109 T
3605 M

Gas Turbine (GT) or Combustion Turbine (CT)
COMBINED THERMAL CYCLE

CYCLE DIAGRAMS
MESQUITE GENERATING STATION

- 1250 MW Net with Natural Gas Fired Combustion Turbines and Duct Burners
- Commercial Operation 2003
GATEWAY GENERATING STATION

- 600 MW Net with Natural Gas Fired Combustion Turbines, Duct Burners, and Chillers
- Commercial Operation 2009
MAJOR EQUIPMENT OF COMBINED CYCLES

- Combustion Turbines
- Heat Recovery Steam Generators
- Steam Turbines
COMBUSTION TURBINES

- Aeroderivatives are generally utilized for simple cycle peaking due to their high simple cycle efficiency and low exhaust gas temperature.
- New combined cycles generally utilize F, G, H, or J Class heavy duty frame type CTGs.
- F, G, H and J Class CTGs have axial exhaust and cold end drives.
- F Class utilize compressor air for cooling hot components (i.e., turbine blades and transition pieces).
- G and J Class machines (MHPS) utilize steam cooling (except M501GAC).
- Current H Class machines (GE and Siemens) do not utilize steam cooling, air cooled.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>F CLASS</th>
<th>G CLASS</th>
<th>H and J CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TURBINE INLET TEMPERATURE</td>
<td>1400 C / 2552 F</td>
<td>1500 C / 2732 F</td>
<td>1600 C / 2912 F</td>
</tr>
<tr>
<td>(approximate)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
From the 1980's to 2000's, we saw 4 primary classes of engines serving the U.S. market:

- Early Frame
- AERO
- E Class
- F Class

Primary Suppliers:
- ABB
- GE
- Westinghouse
- Siemens V-Class
OEMS have filled in the MW gaps, increased MW and improved efficiency
## TODAY’S CT PRODUCT LINE (>850 MMBTU/HR)

<table>
<thead>
<tr>
<th>CT MODEL</th>
<th>MW</th>
<th>Efficiency</th>
<th>CO2, lb/MWh</th>
<th>Nominal 2x1 CC MW</th>
<th>CC Efficiency</th>
<th>CO2 lb/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHPS J</td>
<td>327</td>
<td>41%</td>
<td>1,090</td>
<td>943</td>
<td>61.7%</td>
<td>724</td>
</tr>
<tr>
<td>GE 7HA.02</td>
<td>330</td>
<td>41.4%</td>
<td>1,079</td>
<td>976</td>
<td>61.2%</td>
<td>729</td>
</tr>
<tr>
<td>MHPS GAC</td>
<td>276</td>
<td>39.8%</td>
<td>1,122</td>
<td>826</td>
<td>59.6%</td>
<td>750</td>
</tr>
<tr>
<td>GE 7HA.01</td>
<td>275</td>
<td>41.4%</td>
<td>1,079</td>
<td>813</td>
<td>61.2%</td>
<td>729</td>
</tr>
<tr>
<td>Siemens H</td>
<td>274</td>
<td>40%</td>
<td>1,117</td>
<td>810</td>
<td>60.0%</td>
<td>745</td>
</tr>
<tr>
<td>Siemens F5EE</td>
<td>232</td>
<td>38.8%</td>
<td>1,152</td>
<td>690</td>
<td>58.6%</td>
<td>770</td>
</tr>
<tr>
<td>Alstom GT24</td>
<td>230</td>
<td>40%</td>
<td>1,117</td>
<td>664</td>
<td>58.4%</td>
<td>765</td>
</tr>
<tr>
<td>GE 7F.05</td>
<td>227</td>
<td>39.3%</td>
<td>1,136</td>
<td>688</td>
<td>59.5%</td>
<td>752</td>
</tr>
</tbody>
</table>

**NSPS = 1000 lb/MWh for Larger CTs**
TODAY’S CT PRODUCT LINE

Combined cycle efficiency > 61%
HEAT RECOVERY STEAM GENERATORS

- HRSGs are large air-to-water & steam heat exchangers
- Tube bundles include superheater, reheater, evaporator, and economizer sections

Costanera Repowering, Buenos Aires, Argentina

Manufacturers:
- Alstom
- CMI
- NEM
- Nooter Eriksen
- Vogt Power
HEAT RECOVERY STEAM GENERATOR (HRSG)

- Pressure Safety Valve Silencer
- Steam Drums
- Inlet Ducts
- Blowdown Drum
- Stack
- Outlet Duct

Battleground Cogeneration Plant, Occidental Chemical Corporation
HEAT RECOVERY STEAM GENERATOR (HRSG)

3 HRSG evaporators at different pressures, thus a Triple Pressure HRSG

Hot Water Extraction for Fuel Heating

Point where IP & CRH Steam Combine
HEAT RECOVERY STEAM GENERATORS

Key design parameters are the pinch and approach temperatures

**HRSG Temperature Profile**
Typical 1 Pressure Non-Reheat

- **Gas**
- **HP**
- **LP**

Pinch

Approach

Cumulative Heat Duty ($10^6$ BTU/HR)

T (deg. F)
HEAT RECOVERY STEAM GENERATOR ERECTION
HEAT RECOVERY STEAM GENERATOR ERECTION

Heat Transfer Module (Tube Bundle) Placement

Each bundle may have 12 or more tube rows

Tube to Header Welds
STEAM TURBINES

• Startup (warm up) time requirements vary and play significant factor in combined cycle startup times

• The steam turbine can be purchased with the combustion turbine or can be purchased separately

• Possible suppliers include: General Electric, Alstom, Siemens, Toshiba, Mitsubishi Hitachi Power Systems
SMALL COMBINED CYCLE STEAM TURBINE

- Main steam admissions: either full-arc or partial-arc, tandem compound reheat or non-reheat steam turbines, 50 and 60 Hz subcritical power generation applications.

- Steam turbine features:
  - HP steam 2,415 PSI / 1,050F; Reheat 1,050F or 1,500 PSI / 950F
  - Single HP turbine casing, single IP/LP casing with IP/LP turbine sections
  - Single overall turbine casing, with HP/IP/LP turbine sections
  - Single flow LP exhaust directions: Axial, down, or single side
  - Impulse or reaction design

KEY FEATURES
- Combined casing design – compact foot print, shorter than multi-casing arrangement & eliminates crossover pipe
- Separated casing design – more efficient due to less leakage between turbines
- Reheat more efficient than non-reheat but more expensive

PRODUCT CHARACTERISTICS
- Power rating: Up to 250 MW
- Single-flow LPs: 60 Hz: 26” to 45”
LARGE COMBINED CYCLE STEAM TURBINE

- Main steam admissions: either full-arc or partial-arc, tandem compound reheat steam turbines, 50 and 60 Hz subcritical power generation applications.

- Steam turbine features: HP steam 2,415 PSI / 1,100F; Reheat 1,100F
  - Single casing, opposed flow HP/IP turbine sections & 2- or 4-flow LP turbine
  - Individual casings: HP turbine, IP turbine, and 2- or 4-flow LP turbine
  - LP exhaust directions: Down or single side
  - Variable reaction design
  - Combined stop & control valves

KEY FEATURES
- Single-casing HP/IP section—reduces turbine hall construction cost and shortens installation time
- Individual casing design – more robust and efficient

PRODUCT CHARACTERISTICS
- Power rating: 180–650 MW
- Last Stage Blade Length: 60 Hz: 26“ to 45”
DESIGN OPTIONS FOR COMBINED CYCLES

- HRSG Duct Burners for Raising STG Power
- Inlet Air Cooling (Evaporative or Chillers)
- Fuel Gas Heating
- Startup Time Considerations
HRSG DUCT BURNERS

- Duct firing raises steam turbine power output
- Utilized when grid electrical demand is high
- Duct burner sizing depends on the Customers requirements
- Heavy Duct Firing = Duct Burner Exit Temperature 1500 to 1600 F
- Heavier duct firing results in a greater efficiency penalty
TYPICAL COMBINED CYCLE DESIGN – DUCT BURNERS ON

Design Features:

- 2 CTGs x 1 STG
- Combustion Turbines GE 7FA.04*
- 3 Pressure Reheat
- Includes Duct Burners for 43 MW or 22% Output Boost for Steam Turbine
- Fired Condition
- Duct Burner Exit Temp 1164 F
- Light Duct Firing
TYPICAL COMBINED CYCLE DESIGN – DUCT BURNERS OFF

Design Features:

- 2 CTGs x 1 STG
- Combustion Turbines GE 7FA.04*
- 3 Pressure Reheat
- Includes Duct Burners for 43 MW or 22% Output Boost for Steam Turbine
- Unfired Condition
### OTHER DUCT FIRED 2X1 7FA DESIGN EXAMPLES

<table>
<thead>
<tr>
<th>Project</th>
<th>Alpha (Once Through)</th>
<th>Alpha (Air Cooled Condenser)</th>
<th>Bravo (Mechanical Tower)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Rejection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>F</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>Duct Burners</td>
<td>Fired</td>
<td>Unfired</td>
<td>Fired</td>
</tr>
<tr>
<td>Exit Temperature</td>
<td>F</td>
<td>1164</td>
<td></td>
</tr>
<tr>
<td>Steam Turbine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>MW</td>
<td>238.6</td>
<td>195.9</td>
</tr>
<tr>
<td>Power Increase</td>
<td>MW</td>
<td>42.7</td>
<td></td>
</tr>
<tr>
<td>Power Increase</td>
<td>%</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Throttle Pressure</td>
<td>PSIA</td>
<td>1901</td>
<td>1523</td>
</tr>
<tr>
<td>Plant Net Output</td>
<td>MW</td>
<td>581.6</td>
<td>540.2</td>
</tr>
<tr>
<td>Power Increase</td>
<td>MW</td>
<td>41.4</td>
<td></td>
</tr>
<tr>
<td>Net Efficiency - LHV</td>
<td>%</td>
<td>55.5</td>
<td>56.0</td>
</tr>
</tbody>
</table>

- Three Separate Project Examples
- Same CTG, Different Cycle Designs
- Light Firing Increased STG Output 22%
- Heavy Firing Increased STG Output 75%
- Note Ambient Temperature and Heat Rejection Differences
- Note Change in STG Throttle Pressure from Unfired to Fired Condition
- Sliding STG Inlet Pressure
INLET AIR COOLING (EVAPORATIVE TYPE)

• Combustion turbine inlet air cooling raises CTG power output

• Evaporative coolers are relatively inexpensive, but consume water

• Incorporated into the inlet air filter housing by the CTG OEM

• Evaporative coolers are most effective in arid climates, but are frequently included in plant designs for all types of climates
INLET AIR COOLING (CHILLER TYPE)

• Chillers are expensive, but yield greater CTG power output increase

• Typically sized to reduce CTG inlet air temperature to 50 F from some specific ambient condition

• Typically water is a byproduct, condensed from the ambient air, and can be utilized elsewhere within the power plant

• The chilling heat transfer coil is integrated into the inlet air filter housing by the CTG OEM

• Chilling system designs vary, particularly the fluid passing through the coil that chills the ambient air (typically chilled water)

• Refrigerant types: anhydrous ammonia, R-123, etc

• Unlike evaporative coolers, inlet air chillers yield an efficiency penalty
INLET AIR CHILLED 2X1 7FA DESIGN EXAMPLE

- Chiller primarily increases CTG power
- STG power is increased if it is not already at maximum output due to duct firing
- If STG was already fired to the maximum, duct firing is reduced
- STG power increase is due to increased CTG exhaust energy to the HRSG
- Chiller operation yields slight efficiency penalty
FEEDWATER HEATING

• Combined cycle designs do not use regenerative feed water heaters that are supplied with steam from the steam turbine

• Unlike a traditional Rankine Cycle, the condensate supplied to the HRSG (boiler) should be as cold as possible.

• Recirculation of hot condensate, already heated by the HRSG, will typically be used to raise the condensate temperature to 140 °F before it enters the HRSG
FUEL GAS HEATING

• Fuel gas heating increases the efficiency of the combined cycle

• Low grade heat from the HRSG is used to pre-heat the fuel gas which improves combustion turbine heat rate

• The heated fuel gas temperature will depend on the CTG OEM

• Values between 280 F and 365 F are common

• The temperature must be controlled to a stable set point or the CTG will run back or trip

• Typically feed water from either the LP drum (280 F) or the IP economizer exit (365 F) is utilized to heat the fuel gas
STARTUP TIME CONSIDERATIONS

Startup times are an increasingly important consideration for combined cycles due to the following:

• Startup emissions are often limited by air permits
• Agencies understand startup emissions can be minimized
• Faster startups consume less fuel and thus save the Owner money
• Fast startups allow the operator to hit higher outputs faster, increasing revenue for merchant generators
• Combined cycles will increasingly be required to start and/or change loads quickly as wind turbine farm output and/or solar energy output to the grid varies
Impact of wind generation on power system load

- Wind is intermittent and is a major contributor during low load hours, but only minimal during peak load hours.
- Wind generation requires a generation mix with more operational flexibility to serve the net load.

Addition of wind generation: Net Load Duration Curve becomes more steep.

Wind generation has small (but not zero) impact on peak load.

Wind generation has major impact on low and minimum load conditions.

CHANGING SYSTEM DYNAMICS

**System Load**
- Base Load Generation
- Mid-Merit Generation
- Peaking Generation

**Hours of Operation / Year**
- System Load without wind
- Net System Load with wind

**Wind generation has major impact on low and minimum load conditions.**
AIR QUALITY CONTROL FOR COMBINED CYCLES

New large combined cycles in the United States typically include the following air quality control equipment and features:

- Dry Low NOx burners for the CTG
- Selective Catalytic Reduction (SCR) system in the HRSG for NOx reduction
- Ammonia injection for the HRSGs SCR
- Carbon Monoxide (CO) catalyst in the HRSG for CO and VOC reduction
- Water injection for the CTG while firing fuel oil, but many new combined cycles fire only natural gas
- If the desired fuel (i.e., hydrogen synthetic gas, etc.) is not compatible with available Dry Low NOx burners, water or steam injection maybe required along with “standard” combustors
RENEWABLE GENERATION
COVER ALL MAJOR TECHNOLOGIES

- Multidisciplinary group of more than 300 staff across company
- Services from R&D to turnkey EPC projects
- Experienced in all energy sources:
  - Anaerobic Digestion
  - Biomass
  - Energy Storage
  - Ethanol / Biodiesel
  - Geothermal
  - Hydro
  - Landfill Gas
  - Ocean
  - Solar Photovoltaic
  - Solar Thermal
  - Wind
In-house planning and EPC execution
SOLAR TECHNOLOGIES

There are two types of solar technologies:

- **Solar thermal**: sunlight heats a fluid.

- **Solar photovoltaic (PV)**: sunlight is converted to direct current electricity in a semiconductor material.
SOLAR ELECTRICITY

- **Two Forms:**
  - Photovoltaic (PV)
  - Concentrating Solar Power (CSP)

- **PV is Growing**
  - High Growth (60%)
  - 1.5-2 GW in US

- **CSP in Development**
  - 427 MW in US
  - Several hundred more MW in construction or planned
ADVANTAGES OF SOLAR

- Silent, unobtrusive
- Minimal maintenance (few, if any, moving parts)
- Uses little water (just for cleaning)
- Easy to permit
- Can be placed on existing structures (roof, carport)
- Abundant resource
- Incentives available
- Modular – scalable from 100 kW to 10 MW
CHALLENGES OF SOLAR

- Energy Cost v. Conventional Energy Sources
- Up Front Cost/Project Financing
- Land Use
- Intermittency
FOUR OF THE PRINCIPAL SOLAR THERMAL TECHNOLOGIES

Parabolic Trough

Linear Fresnel Reflector (LFR)

Power Tower (Central Receiver)

Parabolic Dish-Engine
PLANT DIAGRAM
STEAM CYCLE
100% LOAD OPERATING CONDITIONS

- **Main Steam**
  - 854.8 kpph
  - 1451 psia
  - 710.6°F

- **Cold Reheat**
  - 729.5 kpph
  - 275.8 psia
  - 409.7°F

- **Hot Reheat**
  - 729.5 kpph
  - 259.1 psia
  - 714.9°F

- **STG Exhaust**
  - 584.7 kpph
  - 1.103 psia (2.245 in Hg)
  - 105°F

- **Wet Cooling Tower**
  - CW Flow : 62,344 gpm
  - Delta T = 17°F
  - Approx. 1400 gpm makeup water
  - 102°F ambient
DIRECT NORMAL INSOLATION (USED BY CONCENTRATING SOLAR SYSTEMS)

Concentrating Solar Resource of the United States

Annual average direct normal solar resource data are shown. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SU/NREL, 2007) representing data from 1998-2009.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Billy J. Roberts
19 September 2012

Black & Veatch | 29 September 2015
SOLAR PV TECHNOLOGIES

Mono and Polycrystalline Silicon (most PV)

Thin Film (Cd-Te)

Amorphous Silicon

Concentrating
SOLAR PHOTOVOLTAICS ARE EXPANDING

- Turns sunlight into DC power
- Costs are high, but rapidly falling
- Mature with improvements in panels and manufacturing
CHARACTERISTICS OF PHOTOVOLTAICS

• Direct Conversion of Sunlight to Electricity
• Fixed and Tracking Systems
• Few Moving Parts
• Leverages Improvements in Solid State Electronics
• Typically Unattended
• Key issues: Inverter Life and Reliability
• High Capital Cost
SOLAR PV IS BECOMING BIG

Sarnia 80 MW PV Power Plant, Ontario Canada
U.S. PHOTOVOLTAIC SOLAR RESOURCE
(LATITUDE TILT)

Photovoltaic Solar Resource of the United States

Annual average solar resource data are shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states are a 10km satellite modelled data set (SUNY/NREL, 2007) representing data from 1998-2009.

The data for Alaska are a 40km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Billy J. Roberts
19 September 2012
BIOMASS TECHNOLOGY OPTIONS

- Direct combustion
- Gasification & Pyrolysis
- Anaerobic digestion
- Landfill gas
- Fermentation
### RESOURCE AVAILABILITY: BIOMASS AND... WASTE FUELS

<table>
<thead>
<tr>
<th>BIOMASS</th>
<th>COKE</th>
<th>DRIED SEWAGE SLUDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Residues</td>
<td>Dried Sewage Sludge</td>
<td>Waste Paper</td>
</tr>
<tr>
<td>Rice Hulls</td>
<td>Waste Paper</td>
<td>Paper Sludge</td>
</tr>
<tr>
<td>Rice Straw</td>
<td>Paper Sludge</td>
<td>and Waste</td>
</tr>
<tr>
<td>Palm Oil Residues</td>
<td>Waste Paper</td>
<td>Meat Packing Waste</td>
</tr>
<tr>
<td>Bagasse</td>
<td>Waste Paper</td>
<td>Landfill Gas</td>
</tr>
<tr>
<td>Coconut Residues</td>
<td>Waste Paper</td>
<td>Digester Gas</td>
</tr>
<tr>
<td>Cassava Residues</td>
<td>Waste Paper</td>
<td>Manufactured Gas</td>
</tr>
<tr>
<td>Corn cobs</td>
<td>Waste Paper</td>
<td>Ethanol</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>Waste Paper</td>
<td>Corn Stover</td>
</tr>
<tr>
<td>Banagrass</td>
<td>Waste Paper</td>
<td>Black Liquor</td>
</tr>
<tr>
<td>Arundo Donax (E-Grass)</td>
<td>Waste Paper</td>
<td>Furfural Residue</td>
</tr>
<tr>
<td>Distillery Slop</td>
<td>Waste Paper</td>
<td>Compost</td>
</tr>
<tr>
<td>Oat Hulls</td>
<td>Waste Paper</td>
<td>Peat</td>
</tr>
<tr>
<td>Chicken and Turkey Litter</td>
<td>Waste Paper</td>
<td>Wet Distiller’s Grains</td>
</tr>
<tr>
<td>Cow Manure</td>
<td>Waste Paper</td>
<td>Dry Distiller’s Grains</td>
</tr>
<tr>
<td>Hog Waste</td>
<td>Waste Paper</td>
<td></td>
</tr>
<tr>
<td>Railroad Ties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food Waste</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BIOMASS ENERGY

- Biomass Includes:
  - Wood (& Black Liquor)
  - Biogas / landfill gas, etc.
  - Agricultural residues
  - Energy crops
  - Biodiesel / Ethanol

- Typically 0.1-75 MW
- Can be Low Cost
- Available Almost Everywhere
- But, it is not “pretty”
This map illustrates the solid biomass resources in the United States by county. The analysis includes the following feedstock categories: crop residues (2012), forest and primary mill residues (2012), secondary mill residues (2012), and urban wood waste (2012).
WIND ENERGY OVERVIEW

• Largest source of new renewable capacity in the US

• WTG Specs: 1985 2015
  Rotor: 15m 103m
  Hub Height: 20m 98m
  Rating: 50kW 3,300kW

• Typical capacity factor: 30-50%

• Cut-in Wind Speed: 10 - 13 mph

• Project Size: 1 to 300+ MW
ADVANTAGES OF WIND

• One of the most economic renewable technologies
• Uses no water
• Incentives available
• Proven/mature
• Efficiencies growing
• 37 GW US capacity
U.S. WIND RESOURCE AT 80M (NREL)
WHAT IS A UTILITY SCALE WIND FARM?

- Wind Turbines
- Foundations
- Roads
- Collection System
- Electrical Interconnection
- Substation & Transmission
- SCADA System
- O&M Facility
ANATOMY OF A WIND TURBINE

Rotor
Blades
Hub

Nacelle
Generator
Gearbox

Tower

Foundation
TECHNOLOGY FEATURES

- **Electrical System**
  - Variable Speed
  - ZVRT and DVAR

- **Generators**
  - Single Gen vs. Multi-Gen
  - Permanent Magnet Gen

- **Gearboxes**
  - Direct Drive vs. Gearbox
  - Inclusion of Fluid-Based Gearbox Between Main Gearbox and Generator

- **Nacelle vs. Ground-Level Transformers**
WIND TURBINE NACELLE – VESTAS V82
WIND TURBINE TOWER
WIND TURBINE FOUNDATIONS

Design driven by
- Wind loading
- Soil conditions
- Seismic requirements

Mat Foundation
- 50 feet
- 10 feet

P+H Foundation
- 30 feet
EXAMPLE WIND TURBINE FOUNDATIONS

Mat Foundation

P+H Foundation
PROJECT ACCESS ROADS

- Wind turbine access during construction and operation
- Crane access
- Typically 40 ft wide during construction, then 15 ft wide during operation
- Final width graveled, temporary shoulders just compacted
EXAMPLE ACCESS ROAD
TYPICAL COLLECTION SYSTEM METHODOLOGY

- POI or connection to the grid
- Interconnection Transmission Line
- Collector System Station
- Feeders and Laterals (overhead and/or underground)
- Individual WTGs
GEOTHERMAL TECHNOLOGIES

- Direct: Steam from ground goes directly to turbine
- Flash: Hot fluid from ground is “flashed” to steam
- Binary: Hot fluid is run through a heat exchanger

Also... Geothermal (or Geoexchange) Heat Pumps
GEOTHERMAL ENERGY

- Utilization of Thermal Energy from the Earth
- Mature Technology -- 8,000 MW Installed
- Low Cost, Base Load, Dispatchable, Very High Reliability
- But, High Development Cost Risks, Limited Resource Availability
Geothermal Resource of the United States
Locations of Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems (EGS)

- Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources.
- Source data for deep EGS includes temperature at depth from 3 to 10 km provided by Southern Methodist University Geothermal Laboratory (Blackwell & Richards, 2009) and analyses for regions with temperatures ≥150°C performed by NREL (2009).
- Source data for identified hydrothermal sites from USGS Assessment of Moderate- and High-Temperature Geothermal Resources of the United States (2008).
- "N/A" regions have temperatures less than 150°C at 10 km depth and were not assessed for deep EGS potential.
- "*" Temperature at depth data for deep EGS in Alaska and Hawaii not available.

This map was produced by the National Renewable Energy Laboratory for the US Department of Energy. October 13, 2009 Author: Billy J. Roberts
HYDRO

• Most Mature Renewable Energy Technology

• Development in Transition
  • Easy Spots Taken
  • New Developments Expensive, Difficult to Finance
  • Environmentally Sensitive

• Practical Options
  • Existing Dams
  • Existing Unit Upgrades
  • Energy Recovery

Longtan Dam, China
DIFFERENCES BETWEEN RENEWABLE ENERGY PLANNING & STANDARD UTILITY PLANNING

Policy Mandates vs. Least-Cost Planning

- Standard utility planning includes only cost factors
- Renewable planning often driven by government mandates
- Subsidies – offset the renewable energy cost premium

Variability in resource quality that requires analysis with supply curves

- Development in different locations yields different performance and costs
- Distributed generation benefits
DIFFERENCES BETWEEN RENEWABLE ENERGY PLANNING & STANDARD UTILITY PLANNING

Transmission system impacts

- Projects sited at good resources, not ideal transmission locations
- Rural economic benefits

Future cost improvements

- Conventional technologies are mature while renewable technologies are developing

Intermittency – How to establish the value of capacity and energy?

- No fuel price risk (“fuel”, such as wind, is free)
ISSUES AND BENEFITS WITH RENEWABLE ENERGY TECHNOLOGIES

ISSUES

- Everyday production reliability
- Challenging geographic locations
- Cost
- NIMBY

BENEFITS

- No risk with escalating fuel costs
- Environmentally friendly (for the most part)
- Various states have Renewable Portfolio Standards
# Renewable Energy Representative Technology Costs and Characteristics

<table>
<thead>
<tr>
<th>Technology</th>
<th>Size (MW)</th>
<th>Capital Cost ($/kWac)</th>
<th>O&amp;M Cost</th>
<th>Capacity Factor (%)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore Wind</td>
<td>20-100</td>
<td>1,730-2,200</td>
<td>$36/kW-yr + $3/MWh</td>
<td>30-50%</td>
<td></td>
</tr>
<tr>
<td>Geothermal</td>
<td>20-100</td>
<td>5,000-7,000</td>
<td>$27-34/MWh</td>
<td>80-90%</td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>20-100</td>
<td>4,000-6,000</td>
<td>$70-275/kW-yr + $8-9/MWh</td>
<td>78-85%</td>
<td>$3-5/MMBtu</td>
</tr>
<tr>
<td>Solar PV – Fixed</td>
<td>100</td>
<td>1,800-2,400</td>
<td>$30-65/kW-yr</td>
<td>14-30%</td>
<td></td>
</tr>
<tr>
<td>Solar PV – Tracking</td>
<td>100</td>
<td>1,900-2,500</td>
<td>$35-65/kW-yr</td>
<td>16-36%</td>
<td></td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>250</td>
<td>5,600-7,900</td>
<td>$70-75/kW-yr</td>
<td>25-45%</td>
<td>Includes plants with and without storage</td>
</tr>
<tr>
<td>Natural Gas Combined Cycle</td>
<td>500-800</td>
<td>900-1,500</td>
<td>$6.20-7.60/kW-yr + $3.80/MWh</td>
<td>50-75%</td>
<td>$4-8/MMBtu; includes 2x1 7FA and Advanced Class units</td>
</tr>
</tbody>
</table>
LEVELIZED COST OF ENERGY (LCOE) COMPARISON

Notes: B&V estimates from various projects being initiated in 2015 for completion in 2015 and beyond. Does not include any emissions costs or state-specific incentives. Levelized cost of generation reflect life-cycle cost estimates at the output of the power plant (the “busbar”). Capital costs are all-in estimates inclusive of EPC and owner’s costs (development, permitting, etc.). Transmission costs and system integration costs excluded. Land costs are included as an operating cost. These LCOE values reflect a typical range of capacity factors for each technology, and actual capacity factors can vary outside of the ranges shown here. Variable energy resources (wind, solar), do not include storage to firm the resource. Values shown are for typical commercial projects, subject to resource availability described below. Actual projects reaching commercial operation should be expected to be the lower end (and potentially below) the ranges here. Resource availability: Biomass projects are assumed to be greenfield developments using woody biomass fuel. Onshore wind (class 3+) available in many areas of the country except the Southeast; offshore wind available in coastal areas, but substantially more expensive and not represented in this graph. Geothermal limited to Western U.S. Highest quality (capacity factor) solar resource is in Southwest U.S. Costs elsewhere will be significantly higher.
LCOE COMPARISON – WITH AND WITHOUT INCENTIVES

Notes: B&V estimates from various projects being initiated in 2015 for completion in 2015 and beyond. Does not include any emissions costs or state-specific incentives. Levelized cost of generation reflect life-cycle cost estimates at the output of the power plant (the “busbar”). Capital costs are all-in estimates inclusive of EPC and owner’s costs (development, permitting, etc.). Transmission costs and system integration costs excluded. Land costs are included as an operating cost. These LCOE values reflect a typical range of capacity factors for each technology, and actual capacity factors can vary outside of the ranges shown here. Variable energy resources (wind, solar), do not include storage to firm the resource. Values shown are for typical commercial projects, subject to resource availability described below. Actual projects reaching commercial operation should be expected to be the lower end (and potentially below) the ranges here. Resource availability: Biomass projects are assumed to be greenfield developments using woody biomass fuel. Onshore wind (class 3+) available in many areas of the country except the Southeast; offshore wind available in coastal areas, but substantially more expensive and not represented in this graph. Geothermal limited to Western U.S. Highest quality (capacity factor) solar resource is in Southwest U.S. Costs elsewhere will be significantly higher.
LCOE COMPARED TO NATURAL GAS COMBINED CYCLE PLANT

Notes: B&V estimates from various projects being initiated in 2015 for completion in 2015 and beyond. Does not include any emissions costs or state-specific incentives. Levelized cost of generation reflect life-cycle cost estimates at the output of the power plant (the “busbar”). Capital costs are all-in estimates inclusive of EPC and owner’s costs (development, permitting, etc.). Transmission costs and system integration costs excluded. Land costs are included as an operating cost. These LCOE values reflect a typical range of capacity factors for each technology, and actual capacity factors can vary outside of the ranges shown here. Variable energy resources (wind, solar), do not include storage to firm the resource. Values shown are for typical commercial projects, subject to resource availability described below. Actual projects reaching commercial operation should be expected to be the lower end (and potentially below) the ranges here. Resource availability: Biomass projects are assumed to be greenfield developments using woody biomass fuel. Onshore wind (class 3+) available in many areas of the country except the Southeast; offshore wind available in coastal areas, but substantially more expensive and not represented in this graph. Geothermal limited to Western U.S. Highest quality (capacity factor) solar resource is in Southwest U.S. Costs elsewhere will be significantly higher.
Hypothetical Comparison – For Example Only

Source: Black & Veatch Analysis. Note: Hypothetical comparison based on generic project costs and financing assumptions for 2015 projects. Costs likely to vary outside of these ranges based on specific project assumptions. Includes currently available tax credits unless indicated.
REPRESENTATIVE SOLAR LCOE ACROSS U.S.

Source: Black & Veatch Analysis. Note: Hypothetical comparison based on generic project costs and financing assumptions for 2015 projects. Costs likely to vary outside of these ranges based on specific project assumptions. Includes currently available tax credits unless indicated.
HOW DOES AN ENTRY-LEVEL MECHANICAL ENGINEER GET INVOLVED?

**System Engineer**

- Development of system P&ID’s
  - Service/Potable Water
  - Station Air
  - Compressed Gases
  - Wastewater Collection
- System and equipment sizing calculations
  - Centrifugal/Vertical Sump Pumps
  - Air Compressors/Dryers
  - System Piping
- Development of technical specifications for equipment
  - Pumps/Compressors
  - Valves/Miscellaneous Piping Devices

**Pipe Stress Engineer**

- Modeling of piping systems
  - Pipe materials, temperatures & pressures
  - Model supports
  - Thermal growth
  - Wind & seismic activity
  - Verify design meets equipment and code allowables
- Pipe support detail drawings
  - Anchors, rod hangers, springs, struts & shock absorbers
MECHANICAL/CHEMICAL ENGINEERING
TYPICAL DELIVERABLES

PIPING DRAWINGS

PLANT ARRANGEMENT DRAWINGS

HEAT BALANCE DIAGRAMS

CALCS, SPECS, LISTS, STUDIES

PIPING & INSTRUMENT DIAGRAMS
WHAT IS A P&ID?
WHAT IS A PIPING ISOMETRIC?
PIPE STRESS ANALYSIS

Vertical expansion loop with two back to back elbows and anchor support.

Two back to back elbows on the expansion loop (each side) 42% stress range

45% stress range on the two back to back elbows.

Highest stress ratio in expansion case (EXP) 48.5% is at node 3600 at the elbow anchor on the right.
BLACK & VEATCH 3D MODELING WITH INTEGRATED DATABASE MANAGEMENT TOOLS
CAREER RELEVANT COURSEWORK

System Engineer
- **Major Required:**
  - Thermodynamics
  - Fluid Mechanics
  - Heat Transfer

- **Electives**
  - Intro to Combustion
  - Energy Conversion
  - Computer Assisted Design of Thermal Systems
  - Design of Alternative Energy Systems

Pipe Stress Engineer
- **Major Required:**
  - Materials Science & Engineering
  - Statics

- **Electives**
  - Intermediate Mechanics of Deformable Solids
  - Computer Aided Design of Structures
  - Finite Element Analysis
WHAT ARE THE OPPORTUNITIES FOR ENTRY-LEVEL MECHANICAL ENGINEERS IN THE ANN ARBOR OFFICE?

- Design of new gas fired power plants (combined cycles)
- Integration of new air quality control systems (scrubbers) onto existing coal fired power plants
- Life extension projects for existing coal fired power plants
- Opportunities in renewables will depend on the market demand for certain technologies
- Wind turbines and solar PV installation require virtually no mechanical engineering at Black & Veatch
- Biomass and solar thermal do require mechanical engineering at Black & Veatch
- Black & Veatch pursues the projects that are available in the marketplace
Building a world of difference.

Together

BLACK & VEATCH
APPENDIX:
BLACK & VEATCH POWER PLANT PROJECTS
# COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Enmax Energy Corporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Shepard Energy Centre</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>2 X 1 MHPS G</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPC</td>
</tr>
<tr>
<td>SIZE</td>
<td>800 MW</td>
</tr>
<tr>
<td>CHALLENGES</td>
<td>First combined-cycle power plant in Canada to employ G class advanced gas turbine technology.</td>
</tr>
<tr>
<td>VALUE</td>
<td>“G” technology knowledge/engineering and local construction contractor delivering Canada’s most efficient CCGT power plant.</td>
</tr>
</tbody>
</table>
**COMPLETED CT PROJECT**

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Pacific Gas &amp; Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Gateway Generating Station</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>2 x 1 GE 7FA</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPC</td>
</tr>
<tr>
<td>SIZE</td>
<td>600 MW</td>
</tr>
</tbody>
</table>

**NOTABLE ASPECTS**
- Project Completed On Time and Below Budget
- Low Emissions Fuel Gas Dewpoint Heater
- ENR Construction Project of the Year - 2009 Award Finalist
- Winner of *Power Engineering* 2009 Gas Fired Power Plant of the Year
## RECENT SOLAR PV PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Enbridge, Inc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Sarnia Solar Project</td>
</tr>
<tr>
<td>Location</td>
<td>Canada</td>
</tr>
<tr>
<td>SCOPE</td>
<td>Independent &amp; Owner’s Engineer</td>
</tr>
<tr>
<td>SIZE</td>
<td>80 MW</td>
</tr>
</tbody>
</table>

### CHALLENGES
Expand the existing 20 MW solar farm to be the largest solar PV facility in the World, as of 2010.

### VALUE
Provided services to complete a milestone project and added value by assisting in the draft of first-of-a-kind performance testing protocols. The project will generate enough green power to meet the needs of more than 12,000 homes.
## WIND PROJECT EXPERIENCE

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>DTE Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Multiple Wind Energy Projects</td>
</tr>
<tr>
<td>LOCATION</td>
<td>Various locations in U.S.</td>
</tr>
<tr>
<td>SIZE</td>
<td>600 MW program</td>
</tr>
</tbody>
</table>
| SERVICES     | • Comprehensive Owner’s Engineering  
               • Siting study  
               • Wind data collection and analysis  
               • Development support  
               • Layout and constraints analysis |
CWLP DALLMAN UNIT 33 FGD

- Unit Description
  - 190 MWn Unit
  - Research-Cottrell Dual Loop Absorber (circa 1980)
  - Forced Oxidation Limestone

- Execution Model
  - T&M with not to exceed cap

- B&V Role
  - BOP Engineering, Construction Management, Startup and Testing Support

FGD Design Criteria
Increase SO$_2$ removal efficiency to minimum 98%, without the use of additives
Inlet SO$_2$ of 6.3 lb/MMBtu; maximum outlet SO$_2$ of 0.11 lb/MMBtu

Schedule
Scheduled Completion: June 2011
# CWLP DALLMAN 4, SPRINGFIELD, ILLINOIS

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>City Water, Power &amp; Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>New Generation 200 MW Net Coal Plant Firing High Sulfur Coal</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPC</td>
</tr>
<tr>
<td>LOCATION</td>
<td>Springfield, Illinois</td>
</tr>
</tbody>
</table>
| SCHEDULE | Startup in 2009  
Substantial Completion Achieved Early  
Final Completion Delayed by Balance of Plant Problems |
| VALUE   | Owner worked with the Sierra Club to Develop an Overall Program to Reduce Emissions, then Agreed to Set of Criteria |
## RECENT WIND PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Minnesota Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Bison I Wind Project</td>
</tr>
<tr>
<td>LOCATION</td>
<td>Bismarck, North Dakota</td>
</tr>
<tr>
<td>SIZE</td>
<td>80 MW</td>
</tr>
</tbody>
</table>

**SERVICES**

- Permitting and environmental assistance
- Conceptual design
- Detail design of the entire wind project, including:
  - Access roads
  - WTG foundations
  - 34.5 kV collector system
  - 34.5 / 230 kV substation
  - 23 miles of 230 kV transmission line
- Procurement
- Construction specifications and support engineering completion
## COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Canadian Natural Resources Limited</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Horizon Oil Sands Project</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>1 x 1 GE 7FA</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPC</td>
</tr>
<tr>
<td>SIZE</td>
<td>100 MW</td>
</tr>
</tbody>
</table>

### NOTABLE ASPECTS
- Fuel – utilization of refinery off-gas
# COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Entergy / PPG; R.S. Cogen, LLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Riverside Cogeneration Project</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>2 x 1 Westinghouse 501F</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPC</td>
</tr>
<tr>
<td>SIZE</td>
<td>425 MW</td>
</tr>
</tbody>
</table>

### NOTABLE ASPECTS
- Located inside PPG Facilities
- Completed in 22 months on Firm-Price basis
- Met all performance guarantees with an excellent safety record working on a fast track schedule
- Four different steam tie-in conditions
- Used plant’s existing boilers for back-up
## COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>EPCOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Clover Bar Energy Centre</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>2 X 0 GE LMS100</td>
</tr>
<tr>
<td>SCOPE</td>
<td>Engineering, Construction, Startup</td>
</tr>
<tr>
<td>SIZE</td>
<td>200 MW (Total)</td>
</tr>
</tbody>
</table>
| CHALLENGES | • Construction site is within the confines of an existing industrial site.  
               • Re-use of existing circulating water system and river pump house. |
| VALUE    | Providing clean energy mainly during peak demand periods to address local electricity needs. |
## COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>East Kentucky Power Cooperative / General Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>J.K. Smith Generating Station Units 9 &amp; 10</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>2 x 0 GE LMS100</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPC</td>
</tr>
<tr>
<td>SIZE</td>
<td>200 MW (total)</td>
</tr>
</tbody>
</table>

### NOTABLE ASPECTS
- Aggressive engineering schedule to support project
## COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Louisville Gas &amp; Electric Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Tiger Creek</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>4 x 0 GE 7FA</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPCM</td>
</tr>
<tr>
<td>SIZE</td>
<td>680 MW</td>
</tr>
</tbody>
</table>

### NOTABLE ASPECTS
- Self-perform
- All units completed ahead of schedule
- 403 acre greenfield site
## COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Louisville Gas &amp; Electric Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Trimble County Units 5 and 6</td>
</tr>
<tr>
<td></td>
<td>Trimble County Units 7 – 10</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>6 x 0 GE 7FA</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPCM</td>
</tr>
<tr>
<td>SIZE</td>
<td>1020 MW</td>
</tr>
</tbody>
</table>

### NOTABLE ASPECTS
- Self-perform
- All units completed ahead of schedule
- 1,000 acre site located along Ohio river
## COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Samra Electric Power Generating Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Samra Power Station</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>2 x 1 GE 9E</td>
</tr>
<tr>
<td>SCOPE</td>
<td>Consortium Leader, Detailed Design, Site Management, Startup &amp; Commissioning</td>
</tr>
<tr>
<td>SIZE</td>
<td>300 MW</td>
</tr>
</tbody>
</table>

### NOTABLE ASPECTS
- Finalist for Platts Global Energy Awards 2007 Energy Engineering Project of the Year
- Plant output exceeded guaranteed performance by 5%
- Plant constructed on three plateaus separated by 10 meters in height
- Construction logged over 3,500,000 construction hours without a single lost-time incident
### COMPLETED CT PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Sempra Energy Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Mesquite Power Generating Facility</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>2 x 1 GE 7FA</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPC</td>
</tr>
<tr>
<td>SIZE</td>
<td>1,250 MW</td>
</tr>
</tbody>
</table>

#### NOTABLE ASPECTS
- Safety Excellence - +2,500,000 hours worked without an OSHA recordable loss time injury, 1,000,000 hours worked without an OSHA recordable
- 99.83% Availability for the first month of commercial operation
- Block 1 commercial operation achieved 72 days early
- Block 2 commercial operation achieved 57 days early
- Power Magazine’s “Top Power Plant of 2004”
- Southwest Contractor lists the Mesquite Project - Number 1 of the top 20 Projects in Arizona
- 43 percent more efficient than a typical natural gas fueled
## RECENT LM6000 PROJECT

<table>
<thead>
<tr>
<th>CLIENT</th>
<th>Northland Power Incorporated</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT</td>
<td>Spy Hill Peaking Project</td>
</tr>
<tr>
<td>TECHNOLOGY</td>
<td>2x0 General Electric LM6000</td>
</tr>
<tr>
<td>SCOPE</td>
<td>EPC</td>
</tr>
<tr>
<td>SIZE</td>
<td>86 MW</td>
</tr>
</tbody>
</table>

**CHALLENGES**

Project located in remote area of Saskatchewan, with cold weather operation and remote startup and operation.

**VALUE**

Seasoned engineering teamed with a lean and experienced Canadian contractor.