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Low Cost Peaker Installation with "Zero-Hour" Refurbished Aero Engines

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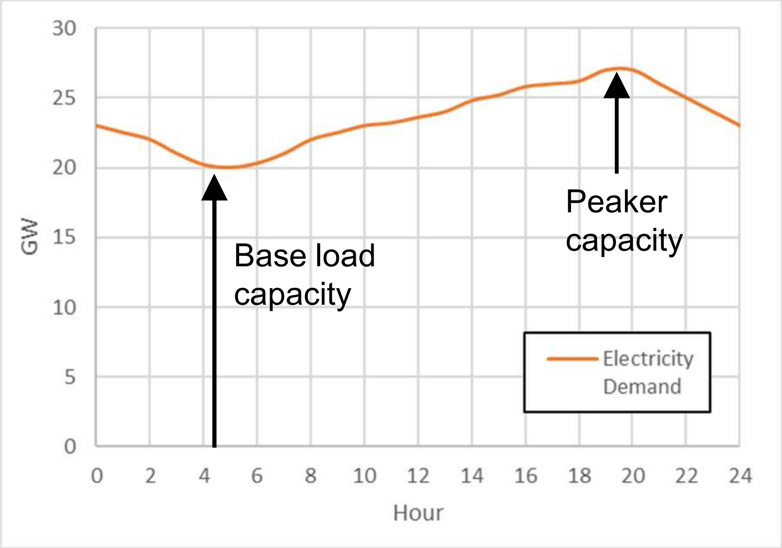
Agenda

1. The need for peaking power
2. Current strategies
   a) Base load plant repurposing
   b) Continental transmission
   c) Energy storage
   d) Natural Gas
3. Low Cost Aeroderivative Gas Turbines
   a) Engine & package overhaul
   b) Standard designs
   c) Vertical Integration
   d) Case Studies

The Need for Peaking Power

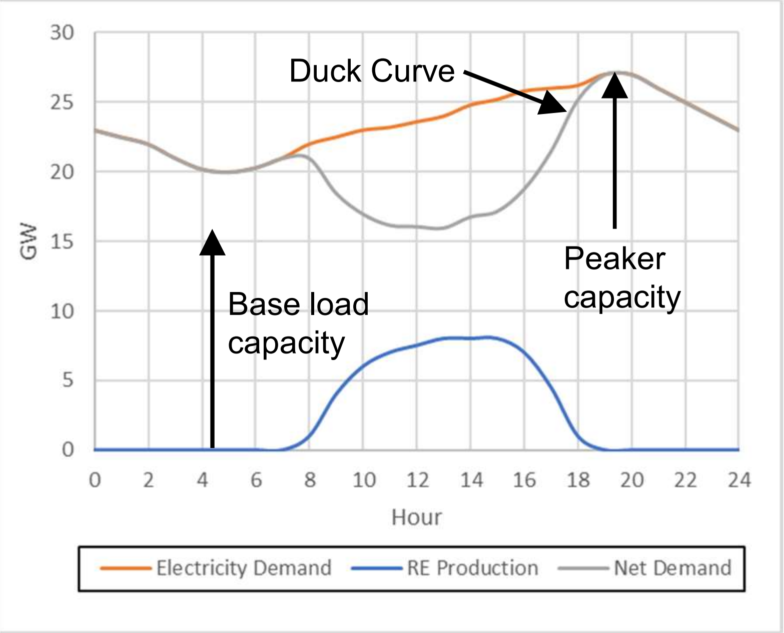
- Historically, electricity demand curves were highly predictable
- Known demand sets local ratios of power plant types:
  - A. Base load facilities
  - B. Peaker facilities



Electricity Demand in California, October 22, 2016. Data from the CISO

The Need for Peaking Power

- Surge in renewable energy challenges this design philosophy
  - Intermittent production
  - Limited output control
- The result is a more volatile net demand curve
  - "Duck Curve" [CISO]
- Peaker capacity vs. base load capacity increases



Net Electricity Demand in California, October 22, 2016. Data from the CISO

Repurpose base load facilities

- Cycle existing base load facilities
- Low CAPEX
- Difficult to stabilize high volatility with low ramp speeds
- Off-design cycling leads to:
  - High maintenance costs
  - Increased CO_2 per kWh

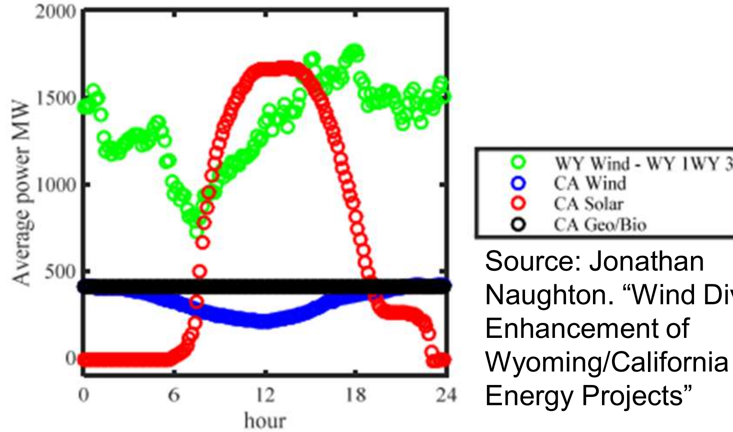
Coal

Combined Cycle HRSG Drum

Continental Transmission

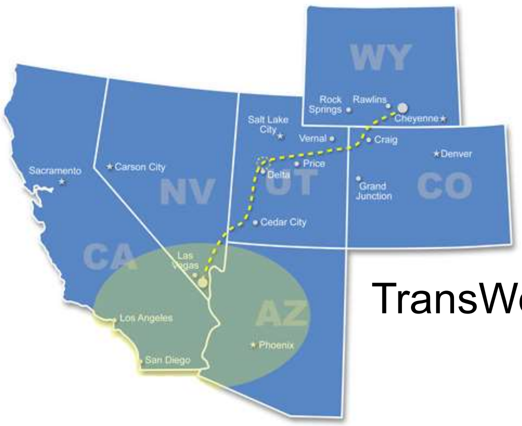
- Join multiple intermittent sources from different regions to smooth net demand curve

- Case Study: “TransWest Express”
  - 730 miles of transmission connecting WY to CA
  - 3GW capacity
  - $3B USD
  - $1,000 USD/kW (*at full capacity, excluding cost of production)
  - 10+ years to permit



Source: Jonathan Naughton. “Wind Diversity Enhancement of Wyoming/California Wind Energy Projects”

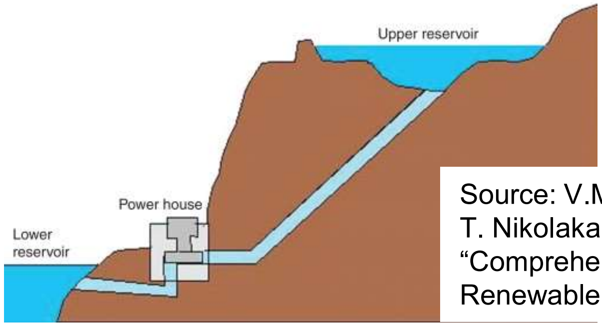
Avg production - June



TransWest Route

Pumped Hydro Storage

- Fill reservoir during low demand, Release during high demand
- High CAPEX ($1,050 USD/kW up to $8,000 USD/kW) [International Renewable Energy Agency (IRENA)]
- Low OPEX
- Low emissions (11-26 g CO_2/kWh)
    - However, CO_2 and CH_4 is released from drowned organic matter)
    - One study calculated theoretical life cycle emissions of 237 g CO_2/kWh for a site in Brazil
- Discharge time of up to 20 hours
- 22 GW capacity in USA
- 174 MW capacity in Canada (Sir Adam Beck Hydro Station)



Source: V.M. Fthenakis, T. Nikolakakis. "Comprehensive Renewable Energy"

Pumped Hydro Schematic

Sir Adam Beck Hydro Station

Batteries – Lithium Ion

- Case Study: “Hornsdale Power Reserve” (Aus)
  - Hundreds of individual Li-ion pods
  - 100 MW / 129 MWh
  - $90.6M USD
  - $900 USD/kW (*excluding cost to produce)
  - 100 days from order to operation

Hornsdale Power Reserve

Pros:
- Strong public support
- Flexible operation
- Portable
- Fast installation
- Low emissions*

Cons:
- Short discharge time (0.5 – 2 hours)
- Short lifespan (7-15 years)
- High water consumption (Li mining)
- Can increase total emissions when charged with polluting sources

Natural Gas Plants

- Cheap, reliable, abundant fuel supply
- Low emissions vs. most other fuels
- Fast response time (<10 minutes):
  - Open Cycle Combustion Turbines (OCCT)

Fuel	(lb)CO_2 / mmbtu
Coal	214.3 - 228.6
Diesel	161.3
Gasoline	157.2
Propane	139
Natural Gas	117

Source: US EIA

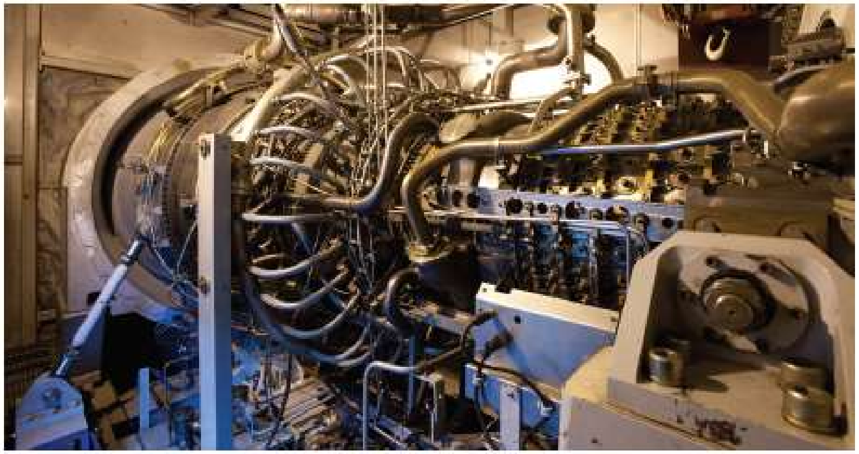
- Reciprocating internal Combustion Engines (RICE)

High-Level Comparison

- Faster start time (down to 5 min)
    - Requires high parasitic load (5MW in a 300MW plant)
- High efficiency at part loads
    - (down to 25%)
- Minimal efficiency loss at high altitude or high temperature
- CAPEX range $890 USD/kW [Red Gate Plant, Texas] to $1342 USD/kW [Source: US EIA]

- Lower OPEX
- Lower emissions of UHCs and other GHG contributors
- Reduced footprint
- Less susceptible to environment (can be installed outdoors)
- Less low frequency noise
- Traditional CAPEX range $700 to $1100 USD/kW [Source: US EIA]
- Reliably below $500 USD/kW using the techniques described here…

Refurbished Aeroderivative Gas Turbines



- LM6000 PC with LP Spray Power Augmentation
  - 48.5MW at ISO Conditions
  - 8,600 Btu/kWh (LHV)
  - Single Annular Combustor
- 41,000,000+ operating hours & 1300+ units shipped
- <10min start
- <430g CO_2/kWh
- Fleetwide availability ~98%
- Minimum continuous load ~25%

Gas Turbine Overhaul

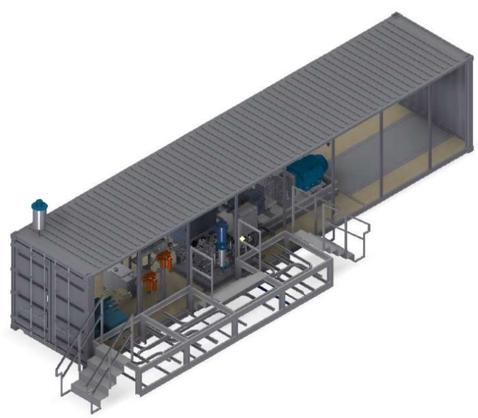
- Disassemble
- Clean/Inspect
- Repair
- Recoat
- Test/certify
- Replace when necessary
- Assemble
- Balance
- Performance test

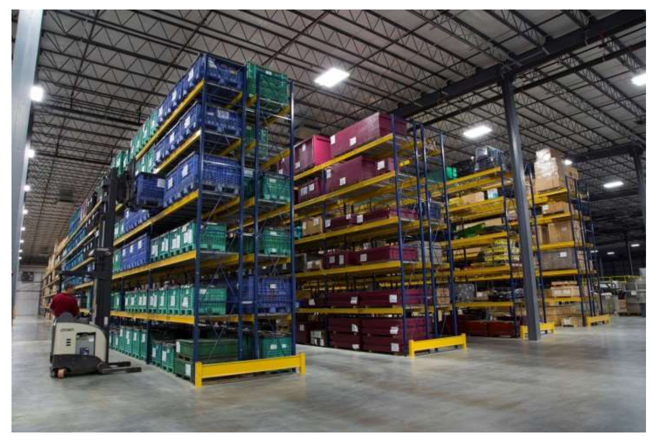
New or Overhauled Package

- Inspect, repair replace:
  - Generator
  - Motors
  - Pumps
  - Wiring
  - Hoses
  - Tubing
  - Enclosure
- Verify controls
- Recalibrate instruments

Plant Standardization (lower cost)

- Standard layout
- Fixed turbine models
- Modular designs
- Pre-fabrication with Quick Connect
- Reliable supply chains
- Inventoried critical components





Vertical Integration (risk mitigation)

- Combined services lead to significant cost savings:
  - Full suite of engine services (including on site test facility)
  - Full package builds
  - Turnkey EPC capabilities
- Life Cycle GT support reduces perceived risk:
  - Performance guarantees
  - Extended warranty
  - Long Term Service Agreements

ProEnergy Services test facility

ProEnergy Services campus

Case Studies

- 3 Sites installed into ERCOT market:
  - < 6 month lead time
  - < USD$500/kW
- Design features:
  - 2x LM6000 PC
  - Common RO/EDI water treatment
  - SCR (2.5ppm No_x, 5ppm NH_3 slip)
  - 2x GSUs, common dead end tower
  - Common PDC
  - Optional black start, evaporative cooling

Chamon

Port Comfort

Conclusions

- Surge in renewables driving:
  - Grid instability
  - Higher utility costs
- Standard gas plants using refurbished engines are better suited to meet peak demands without raising costs:
  - GT Overhaul process well established
  - Standardized plant configurations to reduce lead time and cost
  - Large global inventory of used aeroderivatives
  - Single entity handles full project (Engine → Package → BOP → EPC → O&M)