EGT ENTERPRISES, INC.

and

THIELSCH ENGINEERING

EGT Enterprises, Inc.

Thielsch Engineering, Inc.

Grid-Scale Electricity Storage And Dispatch

Carbon Capture With Power Generation

Association of Consulting Chemists and Chemical Engineers

American Institute of Chemical Engineers, New Jersey Section

ASSOCIATION OF CONSULTING CHEMISTS & CHEMICAL ENGINEERS, INC.

Joint Meeting

March 24, 2015

AIChE NORTH NJ

WHERE TECHNOLOGY CONNECTS

INTRODUCTION

- Renewable Energy Causes Grid Instability
- Massive Electricity Storage Needed
  - Scope of Problem and Potential Storage Solutions
- EGT's Proposed Solution
  - Electric Reaction Technology
  - Direct Carbon Fuel Cells
  - Gas Turbine Technology
- EGT's Technology & Market Development Status

A WORK IN PROGRESS

Energy Storage

Needed to manage intermittent supply of renewables-generated power into the nation's grid

Examples of Electricity Storage Systems

Hydro and Pumped-Hydro

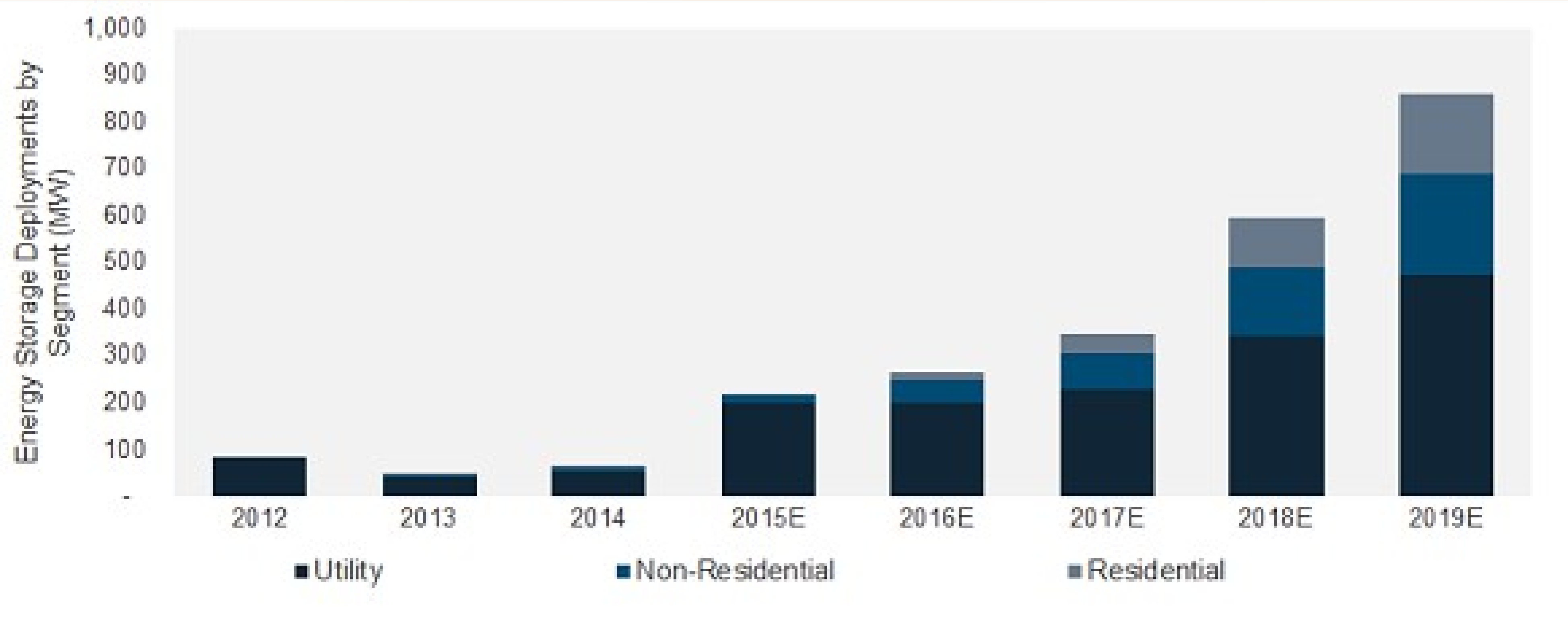
Batteries and Flow Batteries

Flywheels and Compressed Air Systems

Stored Natural Gas as Variable Gas Turbine Fuel

Solar Water-Electrolyzed Hydrogen into Natural Gas

Energy Storage Market Growth



250% Growth 2014 -2015 (est.)
Source: GTM Research
http://www.greentechmedia.com/research/us-energy-storage-monitor?utm_source=email1&utm_medium=email&utm_campaign=USESM

What are Fossil Fuels ?

Natural Gas

Oil

Wood / Biomass ?

Peat

Lignite

Coal

Petroleum Coke

Substantial CO_2 emitted when used for powergen

Fossil Fuels Cause CO_2 Emissions Related to Climate Change

$$CH_4 + 8N_2 + 2O_2 \rightarrow CO_2 + 8N_2 + 2H_2O$$

- **Heavier gaseous fuels, liquid fuels, and carbonaceous solids produce relatively more carbon dioxide than natural gas when burned in power plants for electricity or for any other energy-generation purpose**
- **Produced CO_2 very difficult to separate from N_2**

“Renewable” Fuels Are Needed

Wind

Solar

Hydro

Geothermal

Wood / Biomass ?

Net negligible or reduced CO_2 emitted

when used for powergen

U.S.A. and Germany Percent Renewables on Grid

U.S.A.

2002	9%		
2006	9%		
2013	13%	California	23%

Germany

2010	6%
2014	30%

5X growth in 4 years has created grid stability issues

Renewables Cause Grid Instability

- Wind and Solar are intermittent power generators
  - Hourly, daily, seasonal, regulatory and unplanned

- Other assets must compensate in real time

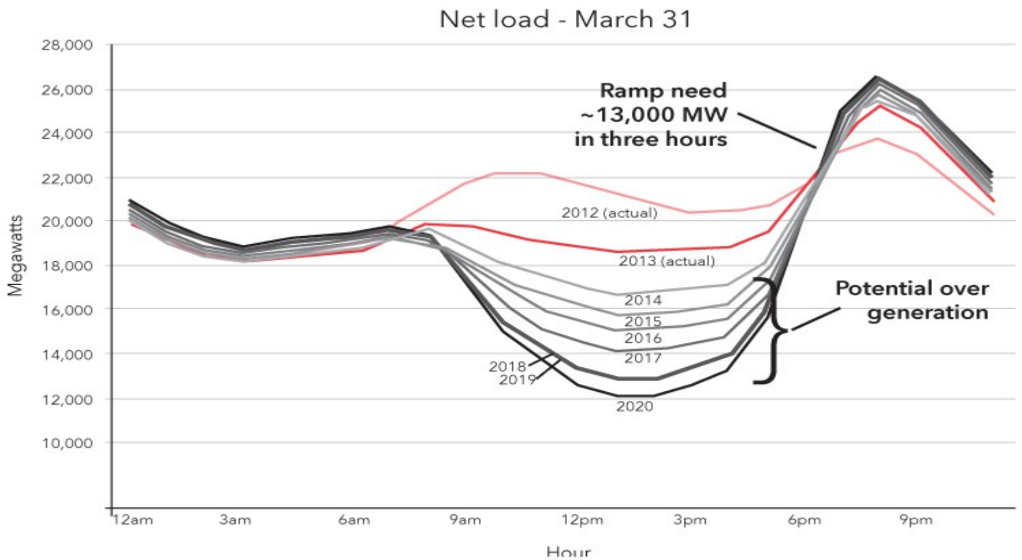
- U.S.A. Risks
  - Nuclear, Hydro and Geothermal are at base load
  - Inflexible Coal plants and Coal plant closures
  - Limited Gas Turbine efficient-operating ranges
  - Slow Nuclear renaissance

2013 - U.S.A. Renewables Generation

Power Source	Summer Capacity (GW)	Percent Total Capacity	Capacity Factor	Annual Energy Billion kWh	Percent Annual Production
Hydro	79.0	7.4	0.4	269	6.6
Wind	60.4	5.7	0.3	168	4.1
Wood	8.2	0.8	0.4	40	1.0
Biomass	5.0	0.5	0.5	20	0.5
Geothermal	2.7	0.3	0.7	17	0.4
Solar	6.2	0.6	0.2	9	0.2
Total	161.7	15.2	0.3	522	12.9

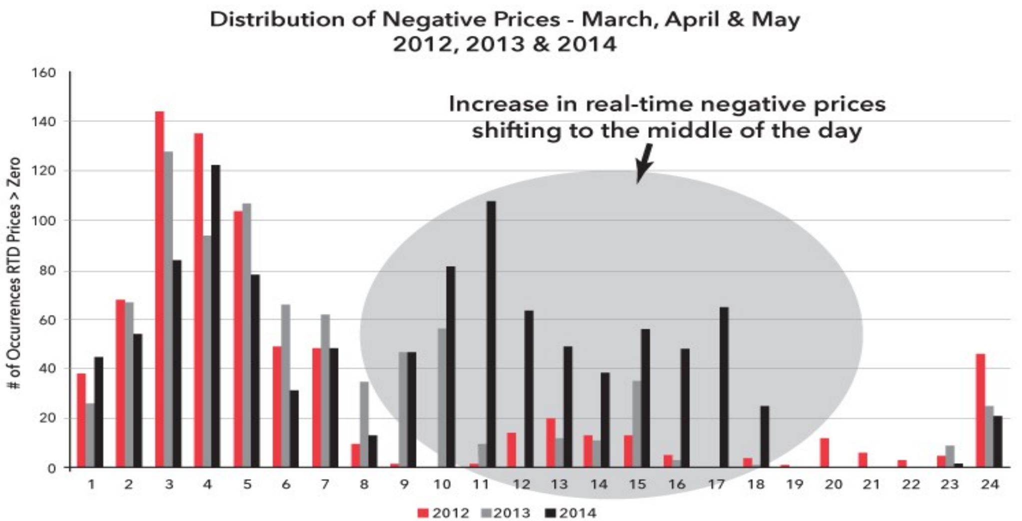
California- "Duck Curve"

Chart 1



Source: CAISO

Chart 2



Source: CAISO

California Has Time To Adjust

GOALS

<u>% Renewables on CAISO Grid</u>

2010	20%
2020	33%
2030	50%

2050 80% reduction from “1990 CO_2”

CALIFORNIA GRID - ISSUES

- Potential Rise in Renewable Portfolio Standard
  - RPS to 40% in 2024 from 33% in 2020 today
- Renewables Unable to Assist Frequency Response
  - They are designed to run at full output
- Renewables Curtailments – 2014 onward
  - Due to Over-Generation by Renewables

California Demand Reduction to Ease Cycling on Fossil Powergen

- Micro-Grids and Distributed Generation
- Combined Heat and Power (District Heat/Cool)
- Circuit-Level Analysis for capital investment
- Building Codes for energy efficiency
- Imported Biomass
- Regulatory Innovation / Curtailment Pricing

Helps to Achieve % Renewable Mandates

CA – Electricity Storage Required

- Market Scheduling from 1 hour to 15 minutes
  - Time-shift the over-generation periods

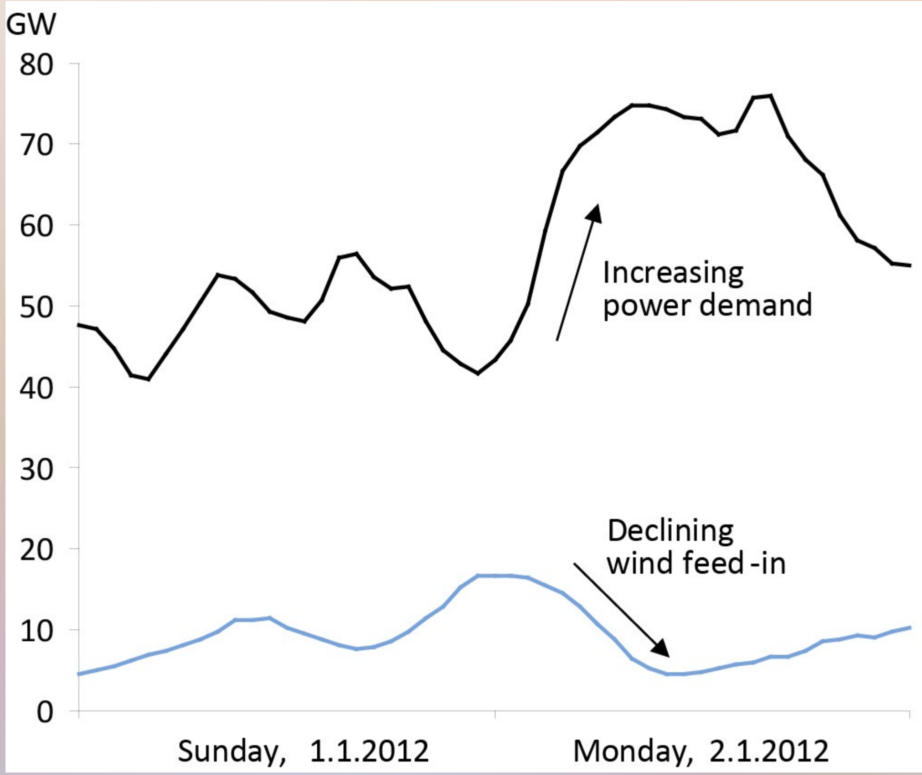
- Change of “Bid Floors” from -$30 to -$300
  - Renewables pay to get their power on the grid

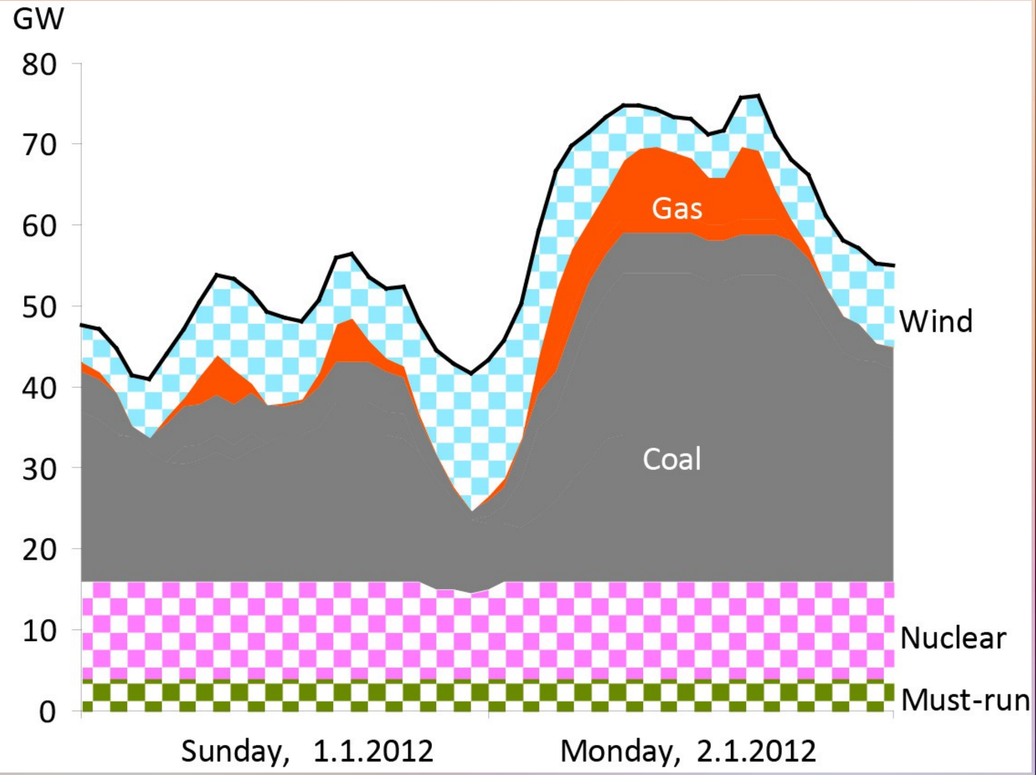
- Out-of-State Backup Commitments

PLUS

GRID–SCALE ELECTRICITY STORAGE

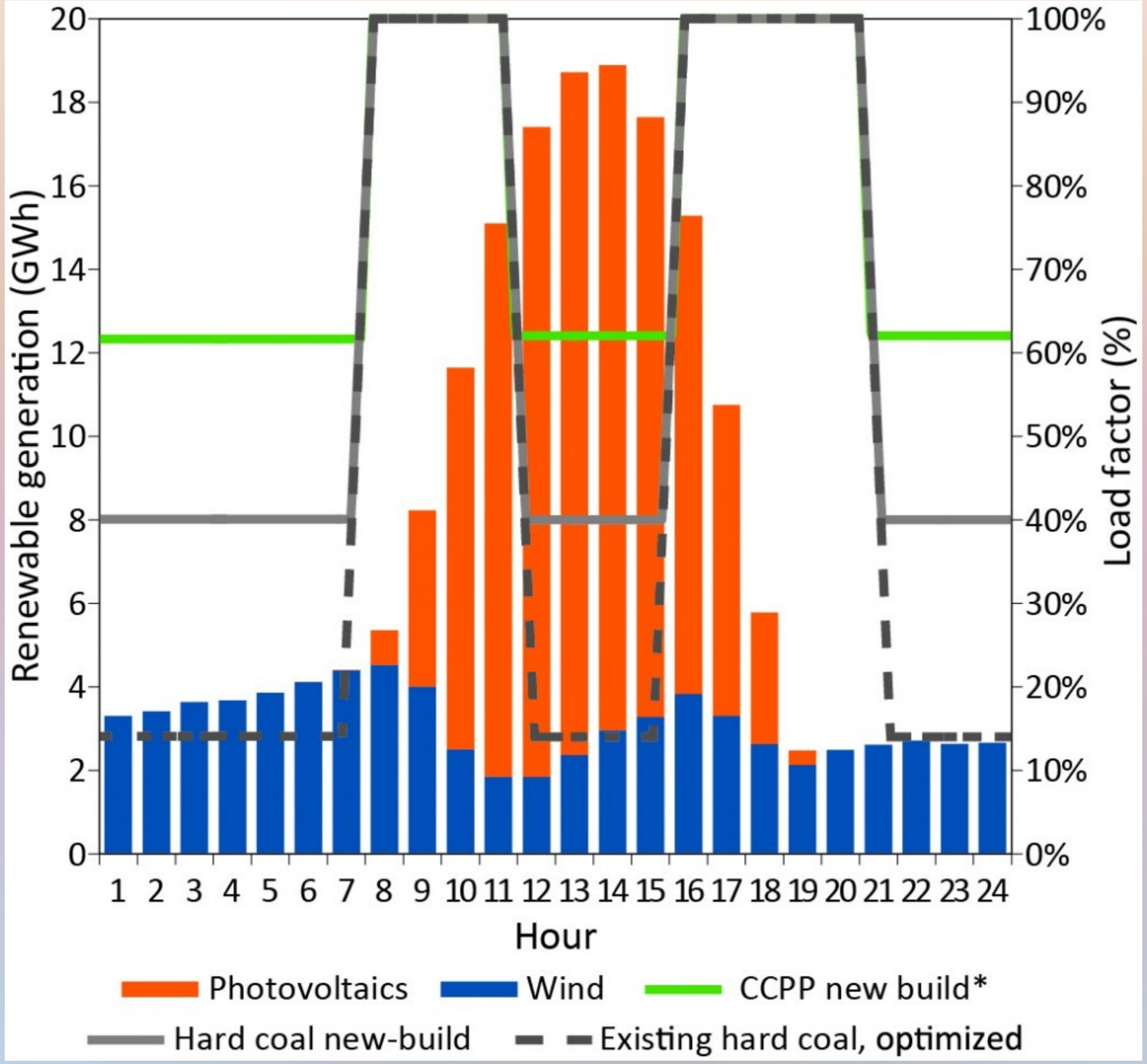
2012 Germany Experience (1)
Wind Supply v. Total Demand





Source: PennEnergy.com

Germany Experience (2)
Response to Imbalance



Germany Experience (3)
Responses and Consequences

- Increased flexibility of legacy coal power plants
- Rapid build of new coal plants with high and/or maximum turn-down flexibility built-in
- No carbon dioxide capture built-in to new plants
- $20 billion/year net subsidy cost to consumers
- Electricity prices to consumers nearly doubled
  - 80% above Euro Average Price
- Electricity subsidy to industry at tax-payer expense
- Many new gas turbine plants remain under-utilized

U.S.A. & Germany Summary

- Emerging situations – “Work in Progress”
- Many concurrent variables in play
  - Efficiency
  - Economics
  - Technologies
  - Federal, State & Local Policies
  - Jobs and Taxes
  - Politics
  - Etc.

EGT's Patents Define A Solution

"Electric Reaction Technology For Fuels Processing"

U.S.A. Patent 7,563,525 (2009)

and

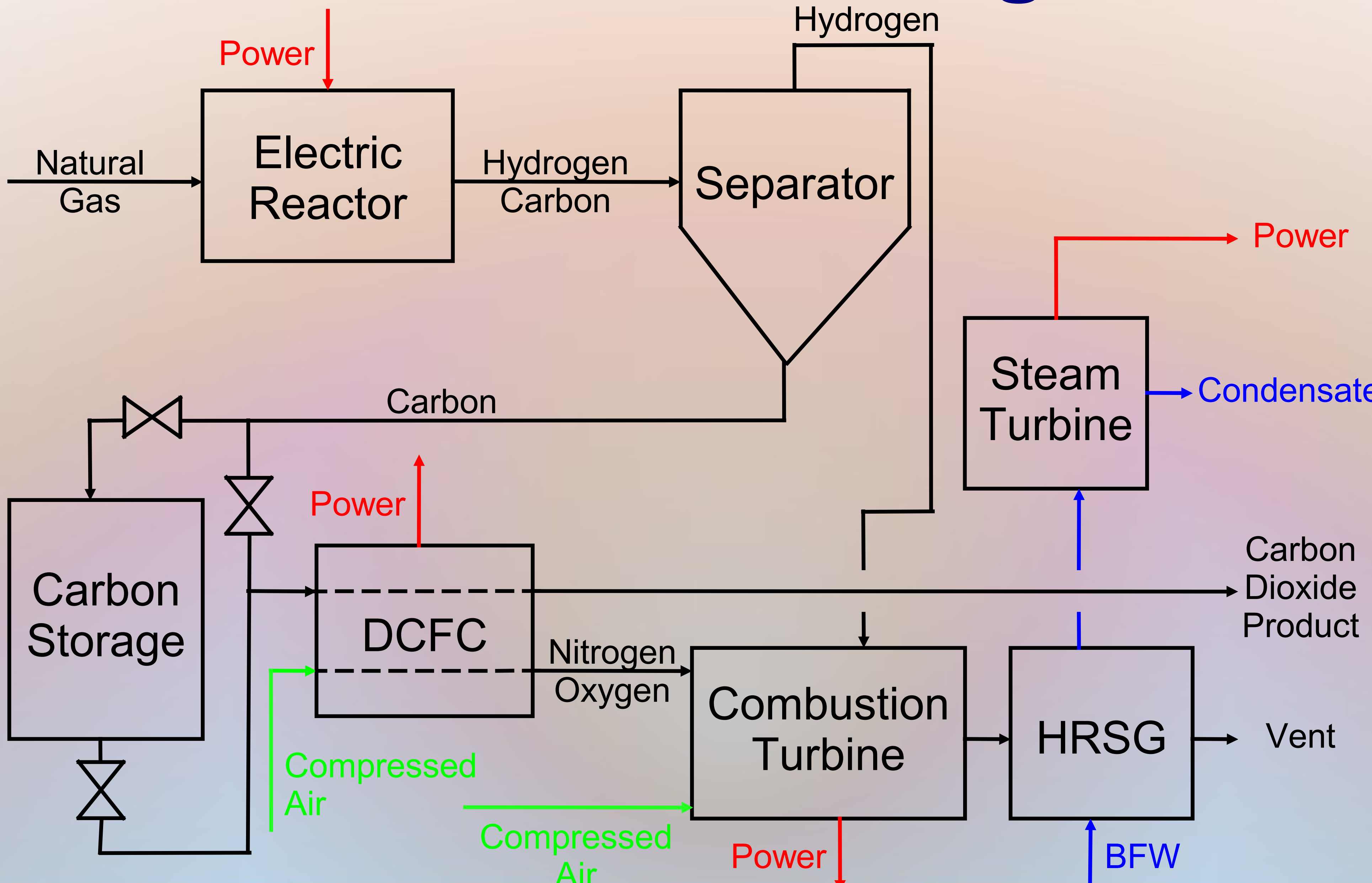
"Carbon Capture With Power Generation"

U.S.A. Patent 8,850,826 (2014)

<u>Electric Reaction Technology Integrated with</u>

<u>Gas Turbine and Fuel Cell Technologies</u>

ERT – DCFC Block Diagram



EGT Process Features

- Electric Reactor decomposes H.P. natural gas into hydrogen and carbon
- Pressurized H_2 continuous fuel for a gas turbine
- Pressurized Carbon stored and dispatched at pressure to fuel a Direct Carbon Fuel Cell
- DCFC electricity is sufficient to run the Electric Reactor and export, on average, 15-20% more than the gas turbine nameplate capacity
- Inherent energy storage and carbon capture

EGT Power – Process Detail

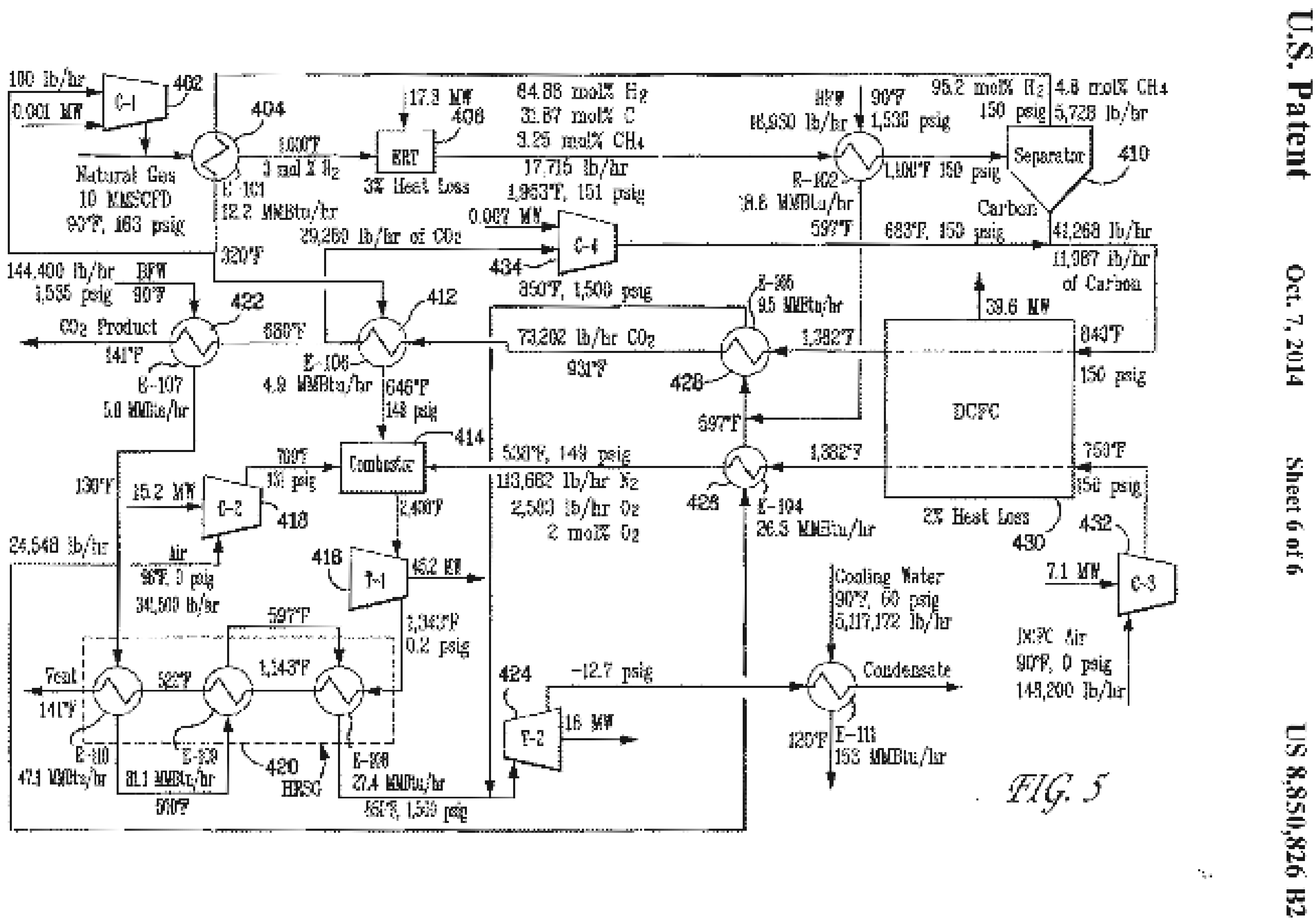


FIG. 5

EGT's Process Benefits

Optimum Profitability

- Electricity sales prices vary continuously by minute, hour, day, day of week, season, wind velocity, solar intensity, tariff requirements (government) and extraordinary events
- Carbon is stored at times of low electricity sales prices with net reduced megawatt-hour sales
- Carbon flows to DCFC during times of high prices with net increased megawatt-hour sales

One Additional Technology Required

Direct Carbon Fuel Cells

$$C + O_2 \rightarrow CO_2$$ + Direct Current Electricity

- Electrochemically convert solid carbon into CO_2 with double the efficiency of hydrogen fuel cells
- Produce a pressurized 100% pure CO_2 product
- Produce a pressurized O_2 - depleted air stream

EGT – DCFC Integration Benefits (1)

- Hydrogen is burned in a gas turbine to generate electricity at Brayton Cycle efficiency
- O_2 - Depleted Air is used as temperature dilutant and oxidant in a gas turbine to generate electricity at Brayton Cycle Efficiency
- Hot CO_2 is used in steam-cogen to generate electricity at Rankine Cycle efficiency

Captures 92+% of CO_2 as pure CO_2

ready for sequestration and sale / beneficial use

EGT – DCFC Integration Benefits (2)

Solar and Wind Integration

- Electric Reactor uses DC for heating fuel gases
  - Solar Cells and Wind Turbines no longer need Direct Current to Alternating Current inverters
  - Eliminates ~5% inverter conversion losses
- "Green Boost" to natural gas for powergen since ERT Power produces 15-20% more electricity from a given quantity of natural gas
- Analogous reduction in "tons CO_2 per megawatt"

First ERT Power Plant Likely At Renewable Site

History of DCFC's

- Invented a century ago but never commercialized
- Attempts in 1990's to use coal as fuel – but failed
  - Rapid electrolyte contamination by ash, sulfur, metals and dirt
- R&D continues at low public financial commitment
- Unknown corporate and private commitments

EGT ready to manage DCFC commercialization with the best concept: <u>MOLTEN ALKALI ELECTROLYTE</u>

DCFC Electrochemistry
SARA, Inc.

Cathode Reaction

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

Anode Reactions

$$C + 6OH^- \rightarrow CO_3^{2-} + 3H_2O + 4e^-$$

$$C + 2CO_3^{2-} \rightarrow 3CO_2 + 4e^-$$

U.S. D.O.E.
Technology Readiness Levels

- ERT – TRL 4
  - Industrial heritage
  - Past the lab stage and ready for demonstration in commercial environment

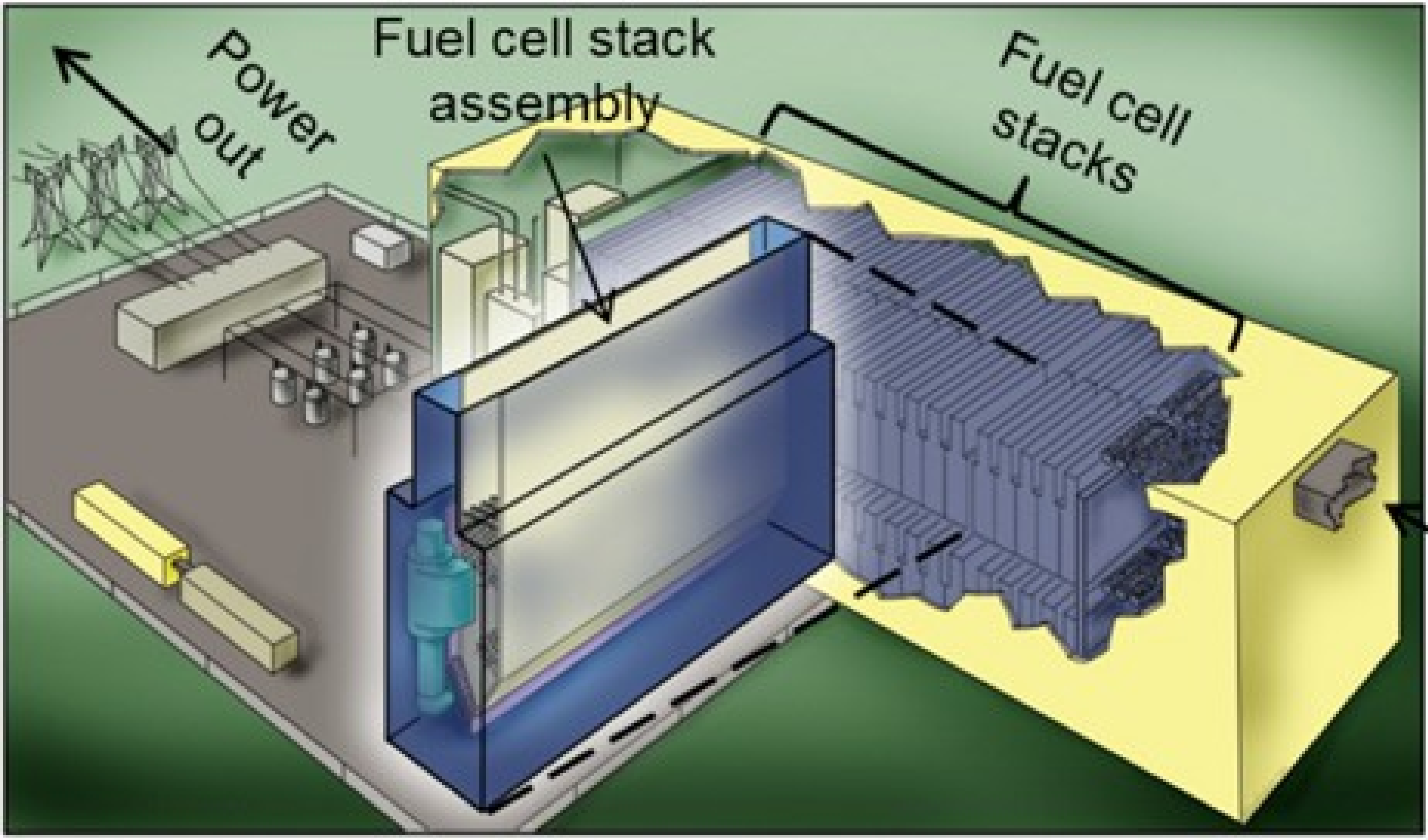
- H2/Carbon Separation – TRL 4

- DCFC – TRL 3
  - Proof of concept at lab scale
  - Industrial prototyping needed to TRL – 4

DCFC Prototypes – To TRL-3
SARA, Inc.

SARA's Technology
Developed Over
Multiple Generations of Successful Prototypes

SARA's Molten Salt – DCFC Vision of TRL-6



MA-DCFC and ERT-Carbon Preferred

- Lowest operating temperature
- Lowest cost materials of construction
- Simplicity and scalability of process reactor
- For any DCFC, ERT-Carbon is pure carbon
  - Made molecule by molecule from decomposition of clean gaseous hydrocarbons
  - No dirt, ash, sulfur, metals or oxygen
  - Sub-micron particle size for high mass transfer rates in molten electrolyte

DCFC Progress Needed

- Electrolyte mixture composition (KOH/NaOH)
- Electrolyte temperature
- Electrode materials and designs
- Industrial reactor concept screening and prototypes to industrial scale TRL - 6

Electric Reactor Status

- EGT has designed (F.E.E.D.) and proposed its patented Electric Reaction Technology for a specific industrial-scale demonstration TRL-6
  - TRL-4 and close to TRL-5
  - 1/12 of carbon black production line
  - 18 month program for EPC and Commissioning
  - EPC by Thielsch Engineering, Inc.
  - Carbon Black manufacturer as Operating Partner

<u>**Awaiting Funding**</u>

EGT Power Plant
Consortium Development

Strategic Partners Sought

Electric and Gas Utility
Solar or Wind Developer and Owner
Gas Turbine and Compressor Manufacturer
Carbon Black Company
Chemical Company with Electrochemistry
Power Plant A&E
Natural Gas and NGL Supplier
Scientific R&D Entitity with Electrochemistry

The Partnering Landscape

Gas Turbine Supplier

Utility Company

Solar / Wind Developer

Gas & NGL Supplier

EGT

Thielsch

Power Plant A & E

SARA /DCFC

CB-Chemical Plant

Electrochem Expertise

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Direct Carbon Fuel Cells http://www.sara.com/RAE/APEG.html

Thielsch Engineering, Inc. Confidential Information

EGT's Patents http://www.egtgroup.com/ennistechnologies/ennispatents.html

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