Integrating Gas and Electric Infrastructure in System Planning and Operations

Case study: ECF Roadmap 2050

Christian Hewicker, Ralph Masiello

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Experience you can trust.

Case example: ECF Roadmap 2050, Phase II

What are the priorities for the next two decades to realize the CO2 reductions in the power sector, in view of the 2050 end state?

Challenges 2010-2030	Proposed end products		
	Technical and economic analysis	**Policy mapping**	**Policy recommendations**
▪ Significant balancing challenges already emerging impacting market prices (Denmark, Spain) ▪ Planned RES investments, new nuclear and EVs will increase balancing challenge ▪ Capital constraints for investment ▪ Demand uncertainty (efficiency, growth after recession, EVs, heat pumps) ▪ Relatively high cost for RES, new nuclear, CCS in next decade ▪ Ability to locate RES is optimal locations and interconnection constraints ▪ Demand management has not picked up to its full potential and continues to face challenges	A. Technical and economic assessment of 2010-2030 and implications for the infrastructure agenda (including gas infrastructure implications) B. Driving cost improvements for RES in the regions C. Functioning and design of power markets D. Mitigation of risks and costs of change	Mapping of current policy failures, options and gaps	

SOURCE: European Climate Foundation (ECF)

Overall objectives of ECF grid modeling

- Assess the impact of different transition paths towards 95% decarbonization in 2050
- Focus on period 2020 – 2030
- Determination of optimal grid expansion and requirements for back-up generation
- Hourly simulation of the European power system, incl. provision of reserve and response
- Zonal representation of the entire European power system by approx. 50 nodes

Need for analyzing impact on gas infrastructure

Back-ground

Power system simulations show need for significant contributions from the gas sector
- Supply of natural gas to ‚normal' gas-fired generation
- Supply of natural gas to gas-fired back-up generation (flexibility)
- Potential reduction of demand as a result of fuel shift (and energy efficiency)

Key questions to be answered

What are the overall implications with regards to the gas demand in Europe?
- Do the power pathways result in significant changes to the expected demand for natural gas on either a European or regional scale?
- Are current plans sufficient to provide enough gas?

Is the gas infrastructure able to provide the required supply and flexibility?
- Is there enough transport and storage capacity to supply annual needs to local customers?
- Is the gas system able to provide sufficient short-term flexibility on a daily basis?

What are the implications in terms of constraints for the power system?
- Are there any constraints that need to be taken into account in power system modeling?
- What might be the approximate costs of relieving such constraints (where possible)?

Are the any important cost implications for the over gas infrastructure?
- What is the impact of the expected changes on the capacity factor of gas networks and storage?
- What might be the impact on the specific costs of gas supply on a European / regional level?

Gas Infrastructure Modeling

1 Power system analysis (multiple scenarios)

- Simulation and assessment of different transition paths for the period 2020 – 2040
- Focus on the implications on the electricity sector and the European power markets

2 Gas infrastructure modeling (selected scenarios)

- Simulation of the European gas infrastructure (2030)
- Using consistent set of assumptions as for power system analysis
- Assumptions on gas gas-fired electricity generation taken from power system analysis
- Focus on identification of issues & constraints (stress test)

3 Re-run power system analysis for critical scenarios

- Re-run power system analysis for scenarios where critical constraints have been identified
- Include additional costs or limits on use of gas as source of back-up and flexibility

Importance of storage in the gas industry

Gas production

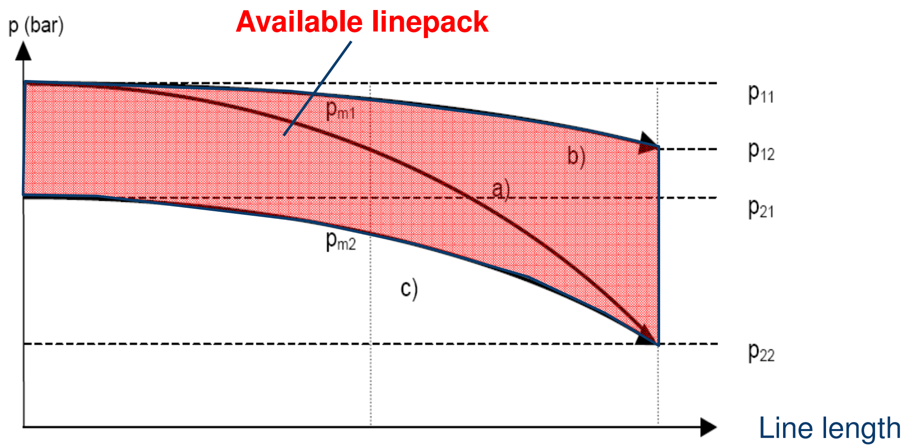
- Gas fields provide inherent storage capability (similar to hydro reservoirs)

Different types of gas storage provide significant flexibility at different time horizons

- Acquifers and depleted fields allow to balance demand on a seasonal to weekly basis but typically provide for very limited flexibility in the short term (diurnal)
- Cavern storage and gas holders provide high operational flexibility and support diurnal as well as weekly to monthly balancing

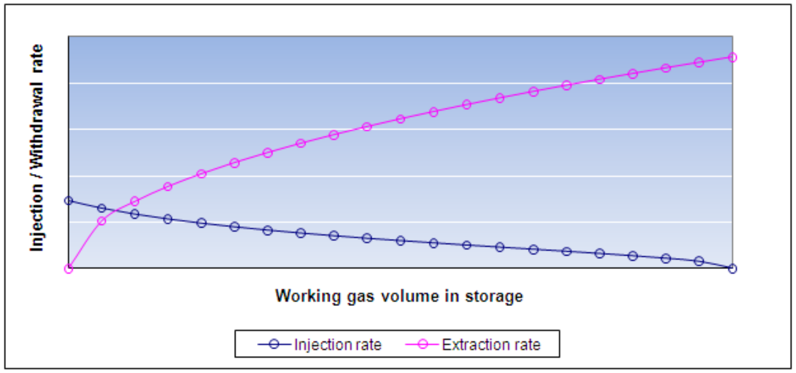
Linepack

- Inherent storage capabilities of gas pipelines offer an important means of flexibility, which often is sufficient to support diurnal up to weekly balancing



Need to consider specifics of gas transport

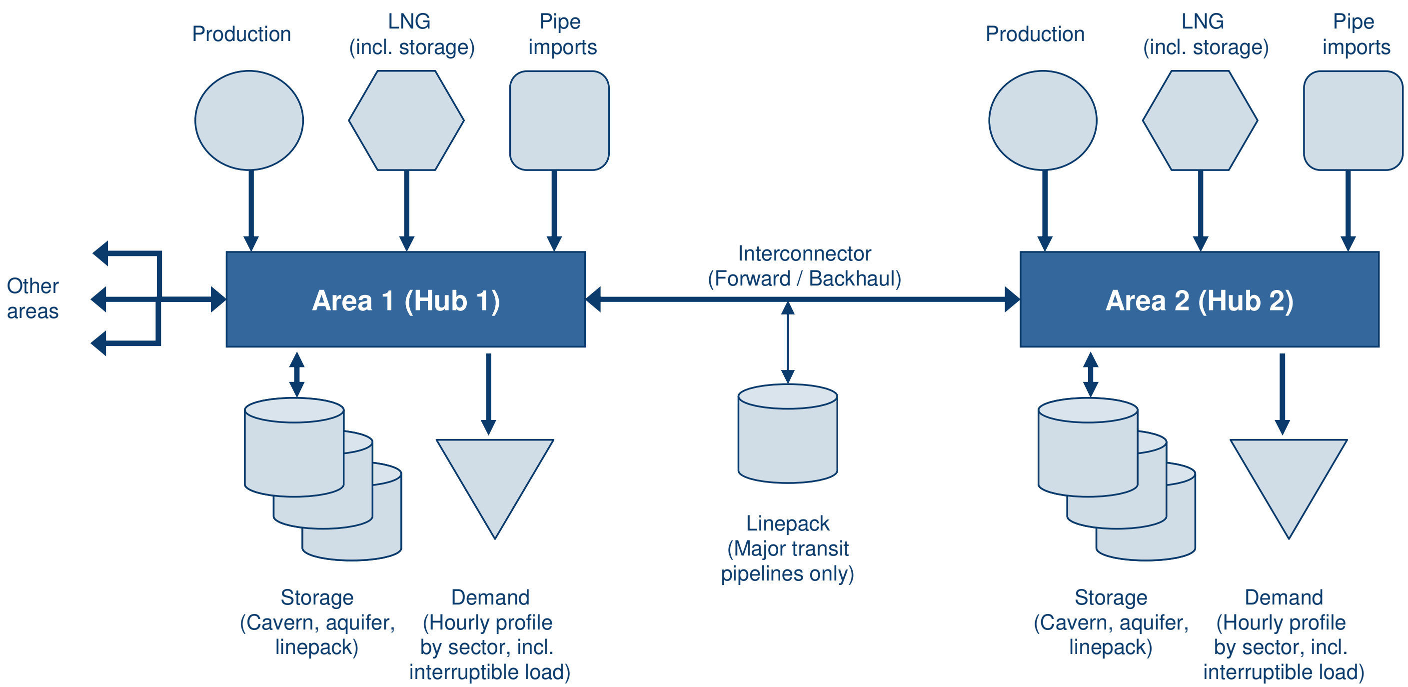
- **Gas network represent a ‚hybrid of DC and AC networks‘**
  - Flows across transport pipelines can usually be directly controlled by means of compressors and valve control (similar to DC lines)
  - At the distribution level, gas flows automatically adjust to pressure differences and pipeline ‚resistance‘ (similar to AC flows / Kirchhoff‘s laws)
  - Gas flows typically are uni-directional
- **Need to account for transport times!**
- **Importance of non-linear relationships**
  - Both transport and storage are characterized by a variety of non-linear relationships
  - In contrast electric networks (DC approximation), it is not easily possible to apply a linear approximation of flows and pressures in a real gas pipeline



KEMA

Zonal model of the pan-European gas markets

- Gas infrastructure model reflects a nodal network, including production, storage, LNG, main transmission routes, line pack and main demand centers
- Flexible and fully scalable network topology
- Ability to add additional constraints and conditions (e.g. gas quality, ToP etc.)



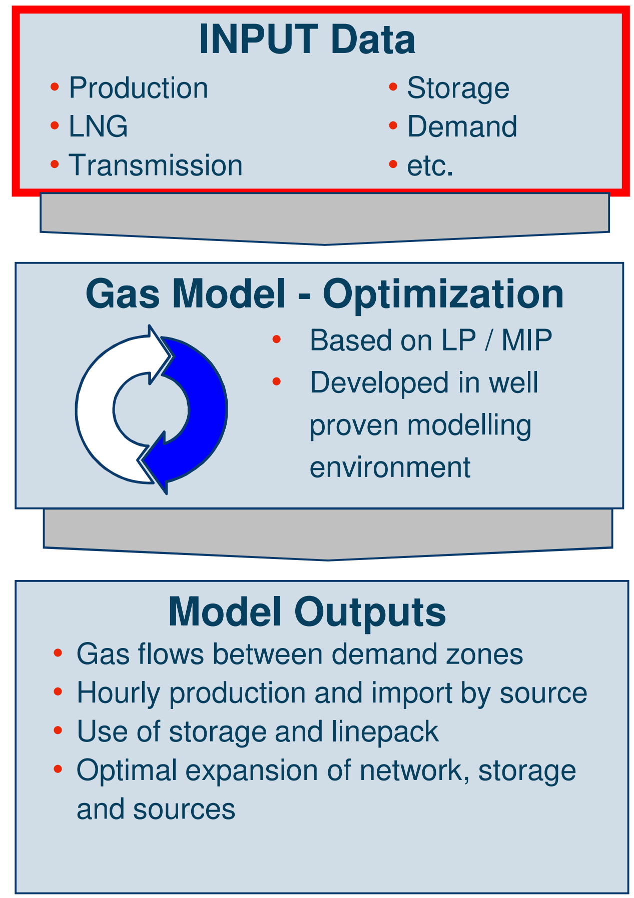
Model characteristics: input data

- **Model input:**

Country specific information on:

- Gas production (where applicable)
- Annual consumption
- Typical demand load profiles (e.g. hourly granulation)
- Cross-border transmission capacities
- Storage facilities per country
- LNG terminal capacities
- Linepack characteristics per country

- All inputs based on publicly available information (ENTSO-G, GTE, GSE, EU, national TSOs etc.)
- Supplemented by expert estimates on technical characteristics and costs where necessary
- National data split by sub-national zones (same as for electricity model)
- Development assumptions e.g. based on PRIMES, European Gas Advocacy Forum report etc.



Model characteristics: combined elements of market and gas transmission system

Model characteristics:

- Network simulation based on zonal representation of European gas markets
- Interconnectors (flow arcs) between demand centers (nodes) with constraints on available cross border capacity
- Detailed representation of production, storage, LNG
- Includes linepack on interconnectors and within regions
- Simulation of yearly time series at a high resolution (hourly time steps).
- Realized as Linear Program / Mixed Integer Program in well proven modeling environment

Objective function:

- Optimal total costs for matching gas demand and supply while taking into account capacity constraints in gas production, transmission networks and storage

INPUT Data

- Production
- LNG
- Transmission
- Storage
- Demand
- etc.

Gas Model - Optimization

- Based on LP / MIP
- Developed in well proven modelling environment

Model Outputs

- Gas flows between demand zones
- Hourly production and import by source
- Use of storage and linepack
- Optimal expansion of network, storage and sources

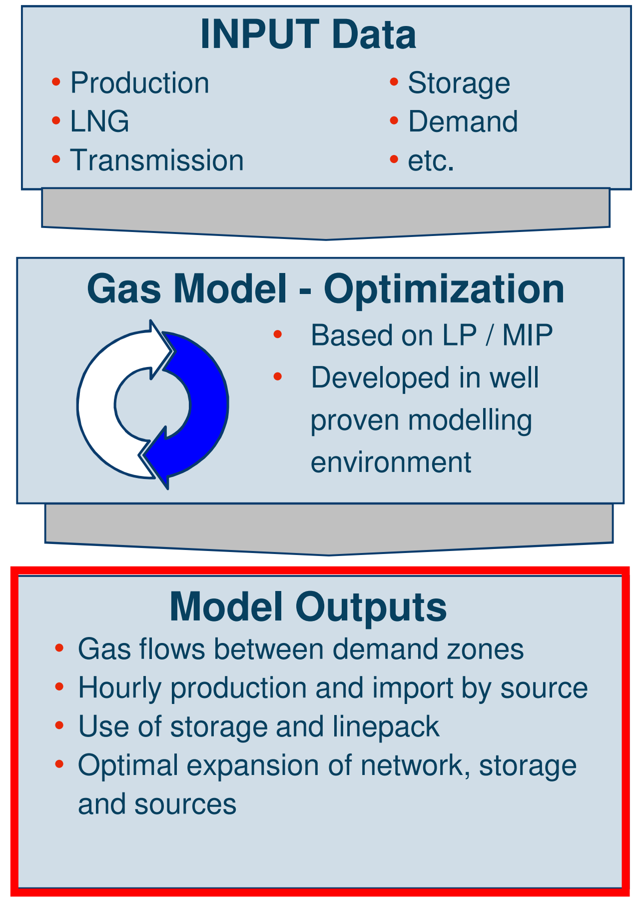
Model characteristics: model output

Model Outputs:

- Gas flows between demand zones (i.e. cross border flows)
- Hourly production and import by source
- Storage and linepack utilization
- Optimal system expansion

Outputs can be used to identify / derive:

- Potential congestion
- Demand for, use of and limits to flexibility
- Most cost effective way to expand the gas infrastructure to resolve congestion and provide sufficient flexibility



Model objects specification

Gas Demand:

- Consumption specified for each demand center
- Hourly demand profiles are generated and included per demand center and per sector:
  - Residential/Household (temperature-dependent)
  - Industry
  - Power generation (input from electricity model)

Transmission:

- Maximum transmission capacity specified for each interconnection between nodes
- Maximum ramp rates to constrain changes in flow rates from hour to hour
- Transport times between different nodes in the network
- Compression costs
- Outage/failure
- Cost of new pipeline capacity

Model objects specification

Production / import / LNG:

- Different types of supply sources of gas are included in the model:
  - Gas produced from local gas fields
  - Import of piped gas from other regions
  - LNG gas produced in regas terminals
- For every gas supply source the following technical parameters are specified in the model:
  - Maximum production capacity (m^3 / hour)
  - Maximum annual production volumes (ACQ's, m^3 / year) plus ToP constraints
  - Ramp rates specifying the speed at which the production levels can be changed over time (%change in output / hour)
  - Production costs $ / m3 (/hour), production start up costs $ / event
  - Unscheduled unavailability of supply sources is specified based on outages/failure (hours/year)
  - For LNG regas terminal additionally the working volume in the terminal and the send-out capacities are taken into account as well.

  → Based on these constraints the upstream supply flexibility and costs are taken into account.

Model objects specification

Means of flexibility :

- Linepack:
  - Linepack represents the buffer capacity a gas transmission network has.
  - Linepack indiviually considered for main transport pipelines and downstream linepack at demand centers (flexibility of local distribution networks)
  - Size of linepack different for all networks
  - Need to consider relation between transport volumes and available linepack as well as time required to build up linepack (and releasing it for longer pipelines)

- Storage:
  - Different types of storages (cavern, aquifer, porous rock)
  - Working volume for storage capacity
  - Injection and withdrawal capacities
  - Operating costs
  - Ramp rates
  - Minimum up/down times

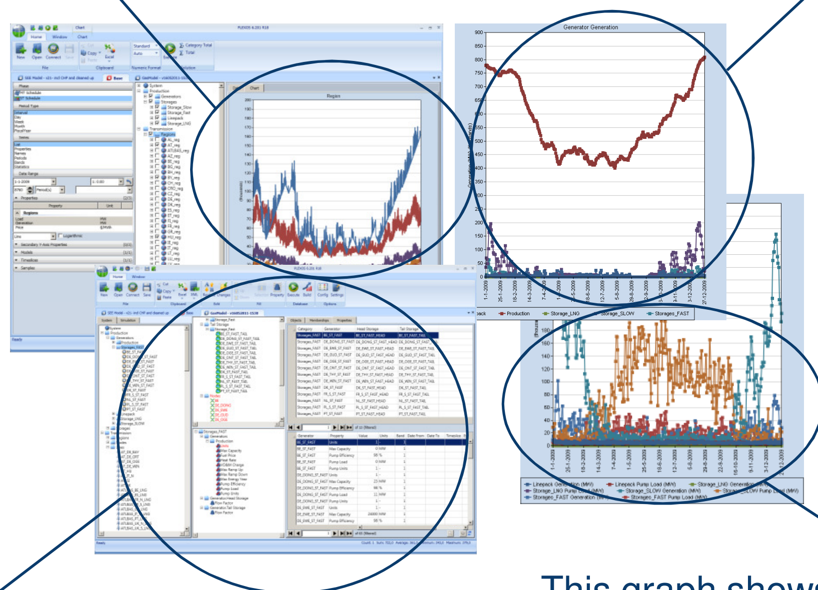
Modeling Environment - PLEXOS

- State of the Art Energy Markets / Operations Tool – SCUC.
  - Widely used Worldwide and by KEMA in EU
  - Adopted by WECC, CA ISO, AEP, MISO, NREL, others in US recently.
    - CA ISO using it for 2012 and 2020 RPS analysis
  - Adopted by KEMA globally
- Object-oriented
  - Ease of adding new market and system elements, objectives, and constraints
  - Multiple solution engines (LP, MIP) to choose from
  - Incorporates DR, DP, Storage Elements already today
  - Basis of modeling Gas and Electric Systems in the Same Tool

The model

This screendump shows the interface in which reports of the model results are generated. This graph shows the load profiles of different demand centres in the network for a whole year.

This graph also shows some first modelling results. The graph shows how the different sources of supply (production = red line) and flexibility are utilized in order to meet demand over a whole year. Next to production, also the utilization of linepack and storage (fast, slow) and LNG is shown. The order of magnitude of these sources is of course much smaller compared to production



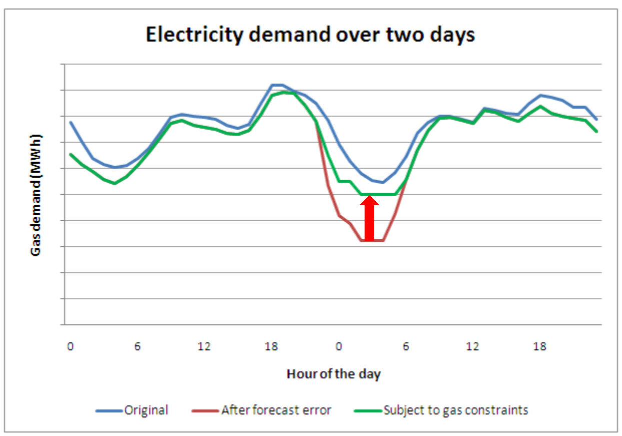
This screendump shows the model building environment. All model objects are categorized (demand, production, tranmission, linepack, storage) Any gas network can be modelled using these templates. The templates give rules and definitions on how objects of various classes behave (technical and commercial parameters are specified here)

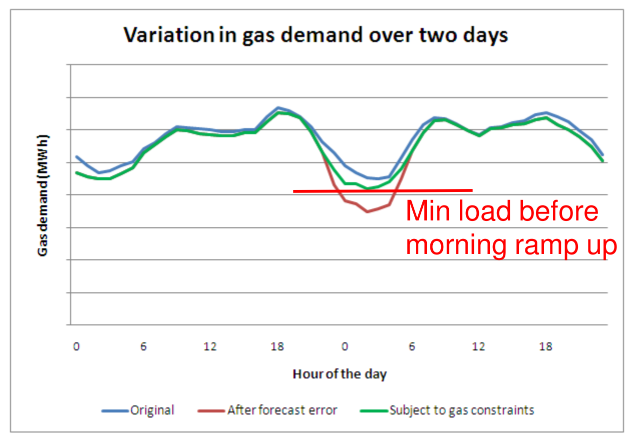
This graph shows the utilization of the different types of storage and linepack the model calculated (What you overall see is injection in summer (brown) and withdrawal in winter (blue)).

Example – linepack restrictions during the night

Accomodation of forecast errors

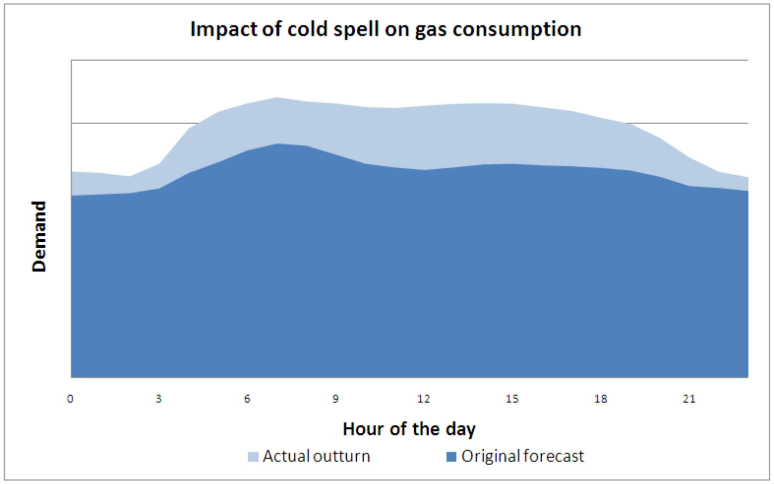
- Example based on CCGT situated at end of gas trunk line
- Original planning based on expected output from wind power plants (left) and combined consumption of domestic gas customers and power generation (right)
- Wind forecast error may result in significant decrease of residual load during the night
- Whilst gas-fired plants would be able to reduce electric output, this reduction could no longer be accomodated by available linepack
- Due to linepack constraints in the gas network, gas-fired plants would only be able to reduce their output to slightly below the original value

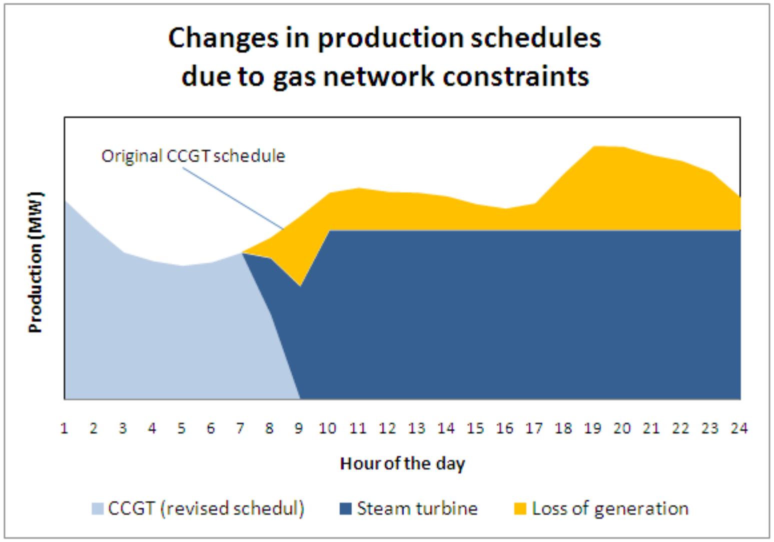




Example – constraints during cold spells

- Example based on two local gas-fired plants
  - Old steam turbine (inflexible, inefficient) with firm exit capacity from gas network
  - Modern CCGT (flexible, efficient) with non-firm exit capacity from gas network
  - On the day-ahead, CCGT has been committed to provide energy and reserves
- Due to unexpected cold spell, both gas and electricity demand increase during the day
  - Additional electricity demand increases prices and results in steamer being committed
  - In combination with increasing gas consumption from domestic consumers, gas supply to CCGT is interrupted
- **Impact on electricity system:**
  - Loss of previously committed power
  - Loss of operating reserves and regulation (not shown in chart)





Modeling Experiences to Date

- Simulations show a reasonable representation of the real behavior of gas networks, production and storage
- Linear approximation of different objects can be flexibly adjusted to desired level of accuracy (but is not intended to replace the use of flow analysis tools)
- Computation complexity of gas storage comparable to hydro optimization
  - but can be adjusted to desired time horizon (e.g. daily unit commitment)
- Model supports full integration with electricity market model
- Care has however to be taken to correctly reflect imperfect coordination between both sectors in practice
- Depending on configuration of local networks, integrated simulation reveals important mutual constraints between natural gas and electric networks
- In particular, gas infrastructure constraints may create serious risks for and/or limit the flexibility of the power system

Thank you for your attention!

Christian Hewicker
Regional Director
Service Line Leader 'Markets & Regulation'
christian.hewicker@kema.com

Ralph D. Masiello
Sr. Vice President, Innovation
ralph.masiello@kema.com

KEMA Consulting GmbH
Kurt-Schumacher-Str. 8
D-53113 Bonn; Germany
Tel +49 228 44 690 00
Fax+49 228 44 690 99

KEMA, Inc.
4377 County Line Rd
Chalfont, PA 18914
Tel (215) 997-4500
Fax (215) 997-3818

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