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[Operational Risk for Integrated Power and Gas Systems Considering Varying Hydrogen Concentrations With High Penetration of Wind]
[Paper ID: 353]
[Session ID: SD2]
[Presented by: Sheng Wang]

Contents

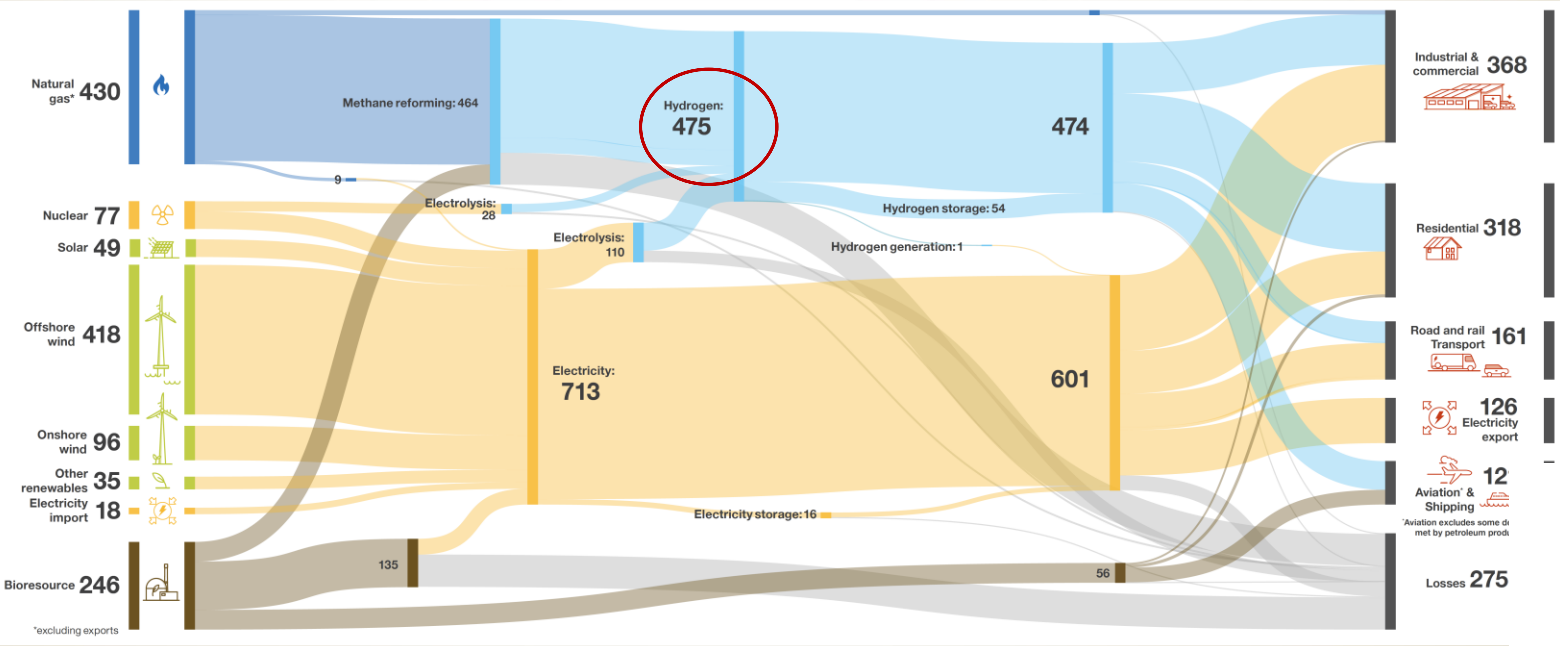
- **Introduction**
- Operational reliability model
- Risk mitigation scheme
- Operational risk indices
- Case Studies

Introduction

----Hydrogen has become an appealing clean energy

In the UK

- Low carbon, easy to produce, easy to transport, easy to storage, and easy to use.
- 5GW of low-carbon hydrogen production capacity by 2030.



2050 energy flows in the UK in the System Transformation scenario

Introduction

Production	**Grey hydrogen** • Using fossil fuels	**Blue hydrogen** • Using carbon capture and storage systems	**Green hydrogen** • Using renewable energies
Transportation	**Tube trailer** • Short distance, small volume	**Hydrogen network** • Small-scale, new infrastructures	**Natural gas network** • Using existing infrastructures
Storage	**Distributed storage** • Small scale	**Centralized storage** • Large scale	**Linepack** • Flexible, easy to access
Consumption	**Industry** • Steel, power…	**Building** • Heating, cooking…	**Vehicle** • bus, railway, shi

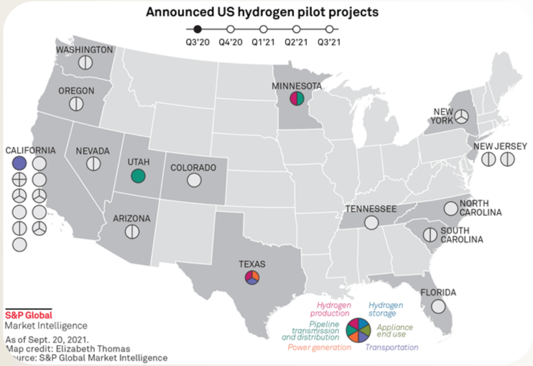
Our scope

Introduction

----Blending hydrogen into pipelines is a popular way

HyDeploy
hydeploy.co.uk

Phase 1	Phase 2	Phase 3
2017	2021	2023
• Keele University • Private network	• Winlaton • Public network	• Enabling Government Policy



2022, New York City

- First natural gas and green hydrogen mixture generation project in the US
- The proportion of hydrogen is up to 35%, and the CO2 emission is reduced by 14%

2022, University of California, California

- Start at 1% and potentially go up to 20% over time.
- Mixed material and steel demonstration will be evaluated base
technical feasibility

…

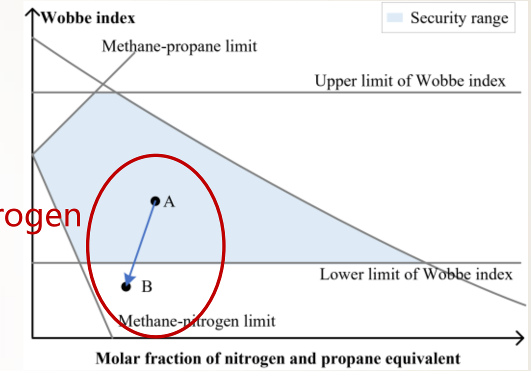
Introduction

---- Potential risks of blending hydrogen

Gas quality

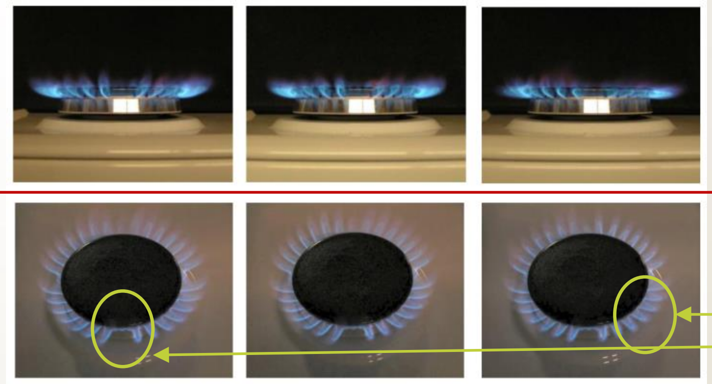
- Low heat value
- unideal combustion

Increase in hydrogen proportion



Combustion dynamics

- Flashbacks
- overheating issues
- potential corrosion of materials



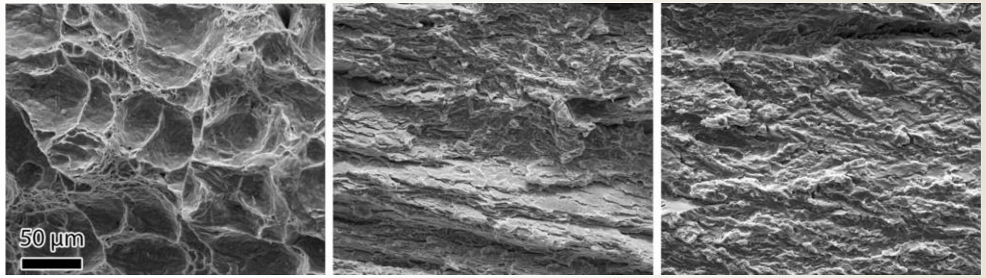
Increase in hydrogen proportion

Introduction

---- Potential risks of blending hydrogen

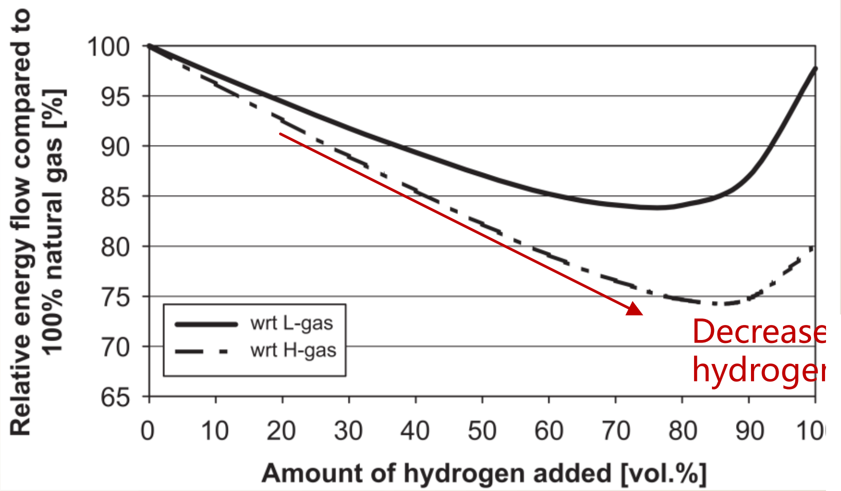
Hydrogen embrittlement

- Corrosion of pipelines, valves, etc.



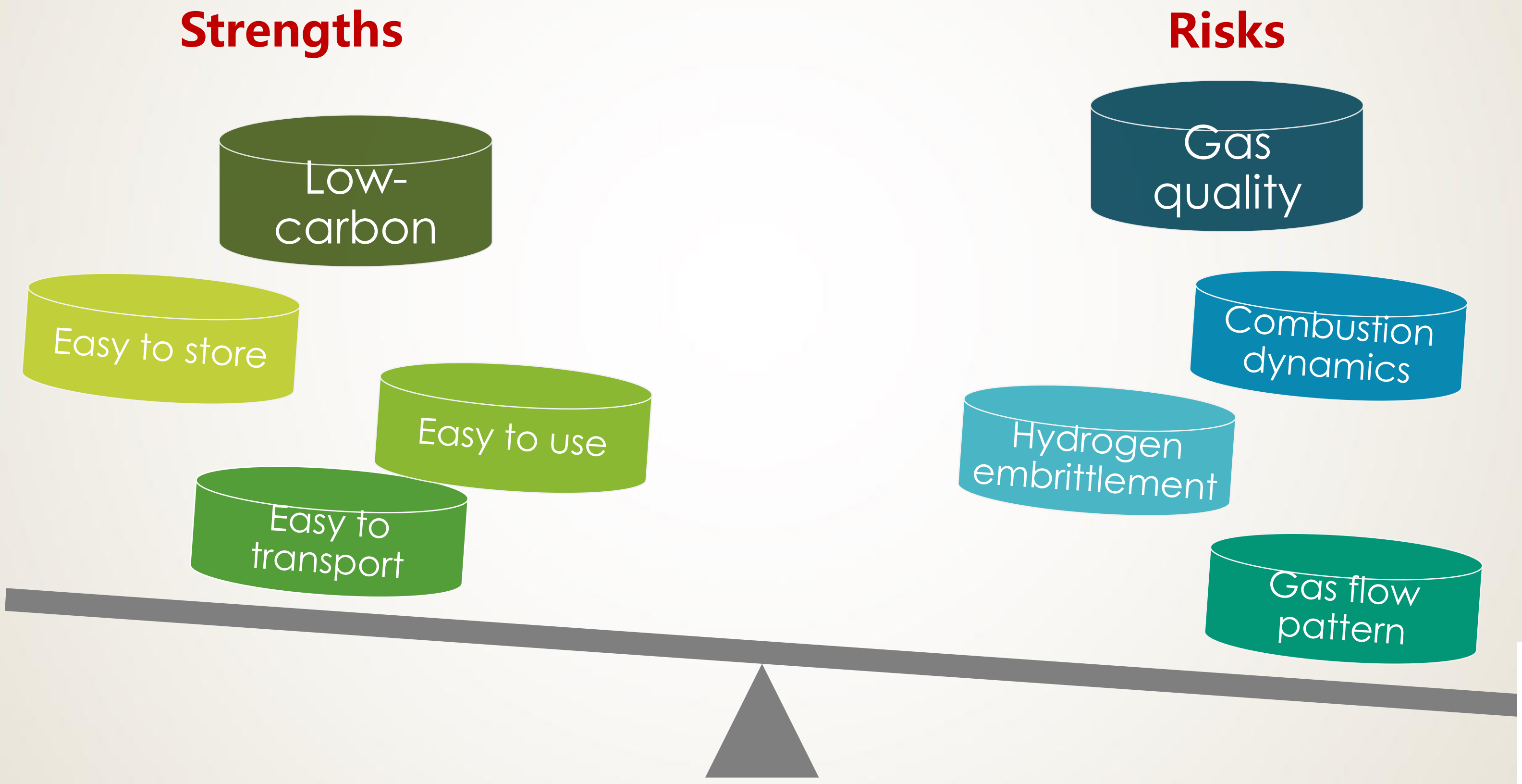
Gas flow pattern

- Change in gas flow pattern
- Linepack swing



Introduction

---- Risk of hydrogen injection needs to be evaluated



Balance

Contents

- Introduction
- **Operational reliability model**
- Risk mitigation scheme
- Operational risk indices
- Case Studies

Operational reliability model

---- PTG system

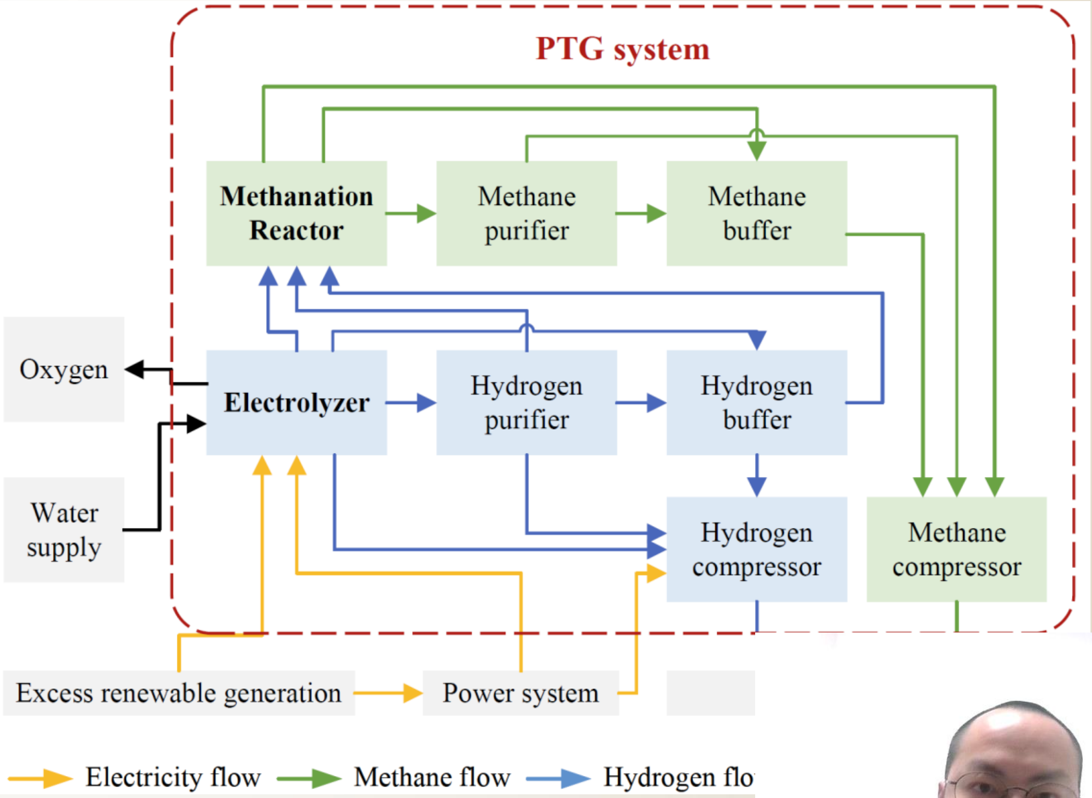
- Subsystem (electrolyzer)

$$u_{i,l}^{el}(z) = A_{i,l}^{el}(t)z^{s^{el}} + U_{i,l}^{el}(t)z^{1-s^{el}}$$

- State probabilities of subsystem

$$A_{i,l}^{el}(t) = \frac{\mu_{i,l}^{el}}{\mu_{i,l}^{el} + \lambda_{i,l}^{el}} + \frac{\lambda_{i,l}^{el}}{\mu_{i,l}^{el} + \lambda_{i,l}^{el}} e^{-\left(\mu_{i,l}^{el}+\lambda_{i,l}^{el}\right)t}$$

$$U_{i,l}^{el}(t) = \frac{\lambda_{i,l}^{el}}{\mu_{i,l}^{el} + \lambda_{i,l}^{el}}\left(1 - e^{-\left(\mu_{i,l}^{el}+\lambda_{i,l}^{el}\right)t}\right)$$

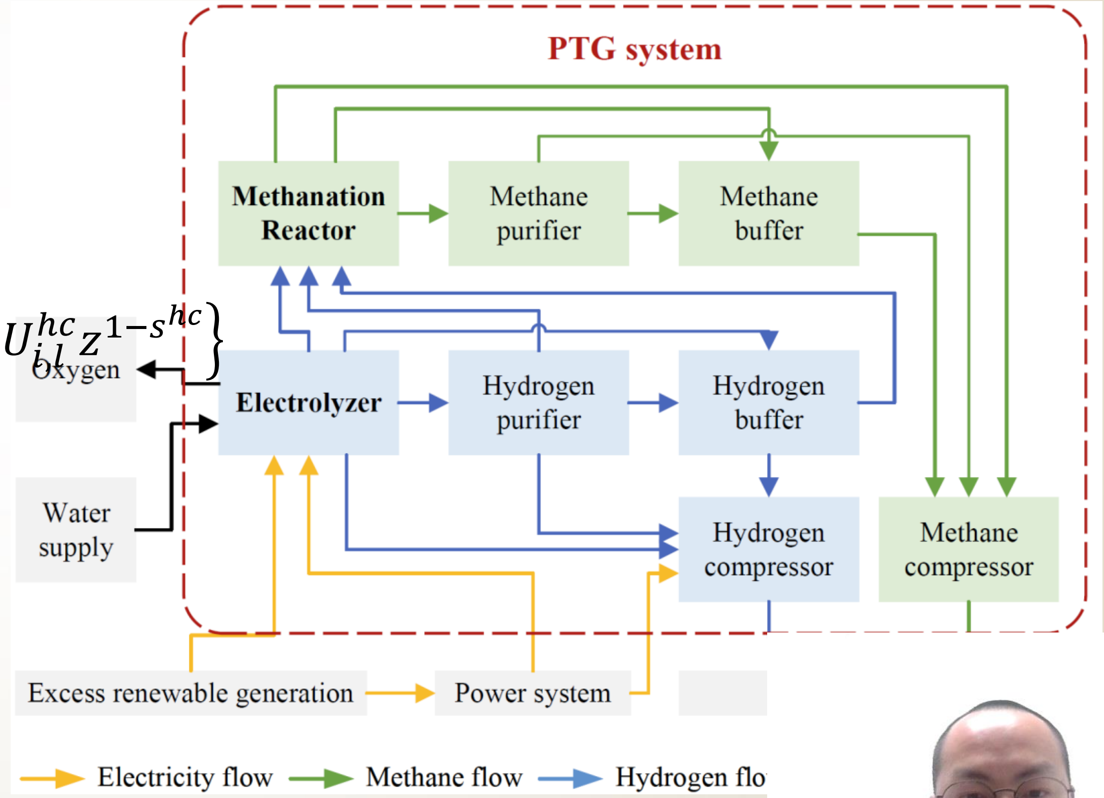


Operational reliability model

---- PTG system

- UGF of hydrogen production capacity

$$u_{i,l}^{1}(z)=\Omega^{s}\{u_{i,l'}^{el}(z)u_{i,l}^{hc}(z)\}$$
$$=\Omega^{s}\left\{A_{i,l'}^{el}z^{s^{el}}+U_{i,l}^{el}z^{1-s^{el}}A_{i,l}^{hc}z^{s^{hc}}+U_{i,l}^{hc}z^{1-s^{hc}}\right\}$$
$$=A_{i,l}^{el}A_{i,l}^{hc}z^{s^{el}s^{hc}}$$
$$+A_{i,l}^{el}U_{i,l}^{hc}z^{s^{el}(1-s^{hc})}$$
$$+U_{i,l}^{el}A_{i,l}^{hc}z^{(1-s^{el})s^{hc}}$$
$$+U_{i,l}^{el}U_{i,l}^{hc}z^{(1-s^{el})(1-s^{hc})}$$



Operational reliability model

---- PTG system

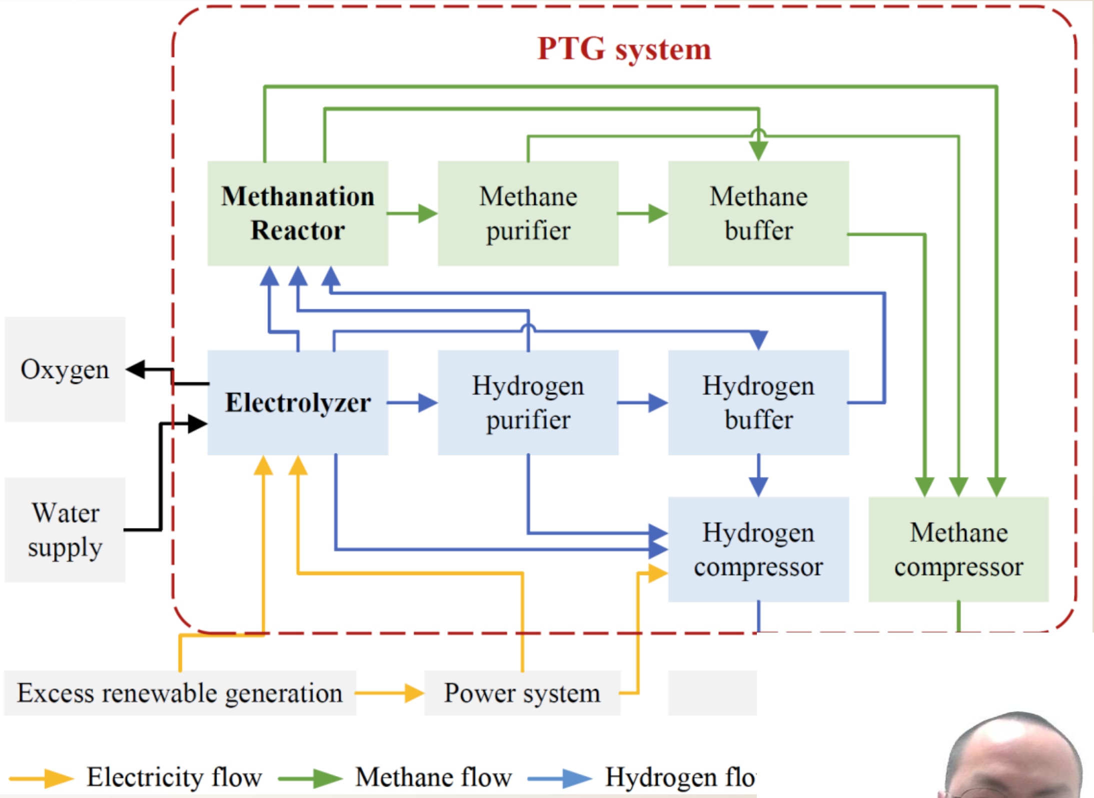
- Availability and unavailability of hydrogen production capacity

$$A_{i,l}^{1} = \frac{\partial u_{i,l}^{1}(z)}{\partial z}\bigg|_{s_1=1,z=1}$$

$$U_{i,l}^{1} = \frac{\partial u_{i,l}^{1}(z)}{\partial z}\bigg|_{s_1=0,z=1}$$

- UGF of whole PTG system

$$u_{i.l}^{ptg}(z) = \sum_{h\in\mathcal{H}} A_{i,l}^{ptg,h} z_h^{s_h} + U_{i,l}^{ptg,h} z_h^{1-s_h}$$



Operational reliability model

---- PTG system

- Physical model of PTG in different states

$$q_{i,l}^{ptg} = \left[q_{i,l}^{me} + q_{i,l}^{me,ds} - q_{i,l}^{me,ch}, q_{i,l}^{hy} + q_{i,l}^{hy,ds} - q_{i,l}^{hy,ch}, q_{i,l}^{ox}\right]$$

$$g_{i,l}^{ptg}\eta_{i,l}^{el}$$

$$= (1 + s_1 M)GCV^{hy}\left(q_{i,l}^{hy} + q_{i,l}^{hy,ch} - q_{i,l}^{hy,ch}\right)$$

$$+ GCV^{me}/\eta_{i,l}^{me}(1 + s_4 M)\left(q_{i,l}^{me} + q_{i,l}^{me,ch} - q_{i,l}^{me,ch}\right)$$

$$0 \le g_{i,l}^{ptg} \le (1 - s_1)g_{i,l}^{ptg,max}$$

$$Q_{i,l,k}^{hy} = Q_{i,l,k-1}^{hy} + q_{i,l,k}^{hy,ch} - q_{i,l,k}^{hy,ds}$$

$$Q_{i,l,k}^{me} = Q_{i,l,k-1}^{me} + q_{i,l,k}^{me,ch} - q_{i,l,k}^{me,ds}$$

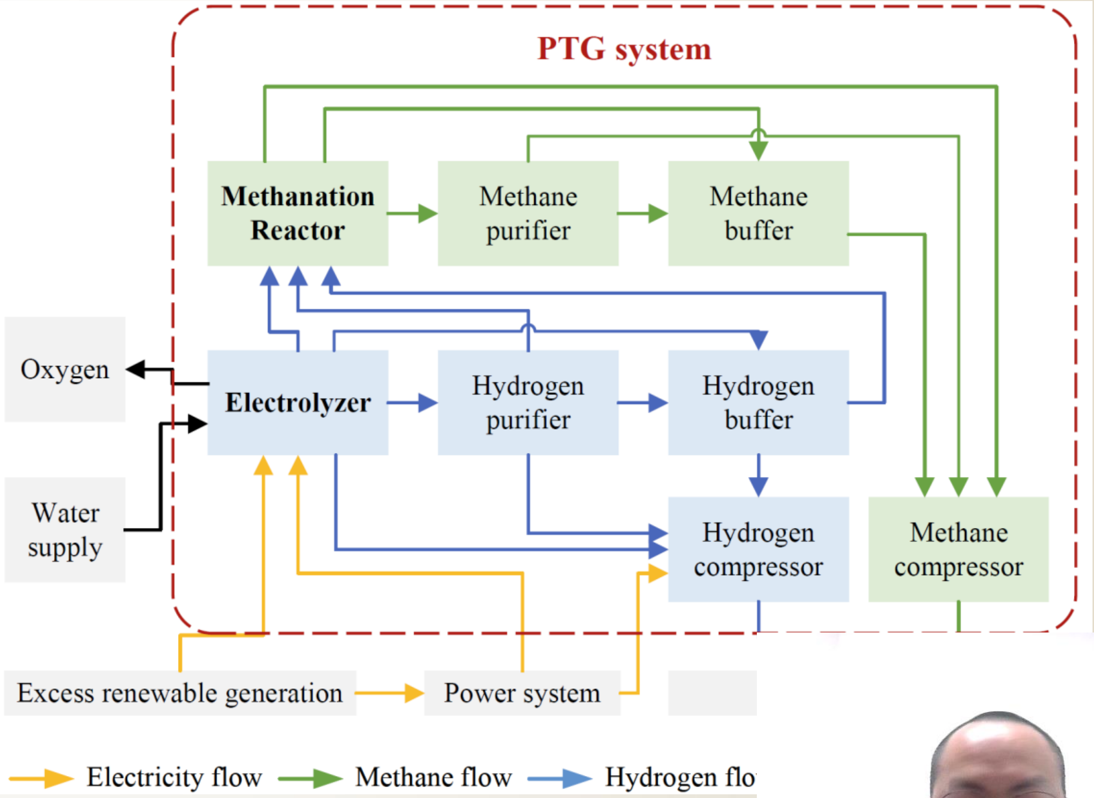
$$0 \le \left[Q_{i,l}^{hy}, Q_{i,l}^{me}\right] \le \left[Q_{i,l}^{hy,max}, Q_{i,l}^{me,max}\right]$$

$$0 \le \left[q_{i,l,k}^{hy,ch}, q_{i,l,k}^{hy,ds}\right] \le s_3\left[q_{i,l,k}^{hy,ch,max}, q_{i,l,k}^{hy,ds,max}\right]$$

$$0 \le \left[q_{i,l,k}^{me,ch}, q_{i,l,k}^{me,ds}\right] \le s_6\left[q_{i,l,k}^{me,ch,max}, q_{i,l,k}^{me,ds,max}\right]$$

$$q_{i,l}^{ox} = s_2\alpha^{hy}\left(q_{i,l}^{hy} + q_{i,l}^{hy,ch}\right) + s_5\alpha^{me}\left(q_{i,l}^{me} + q_{i,l}^{me,ch}\right)$$

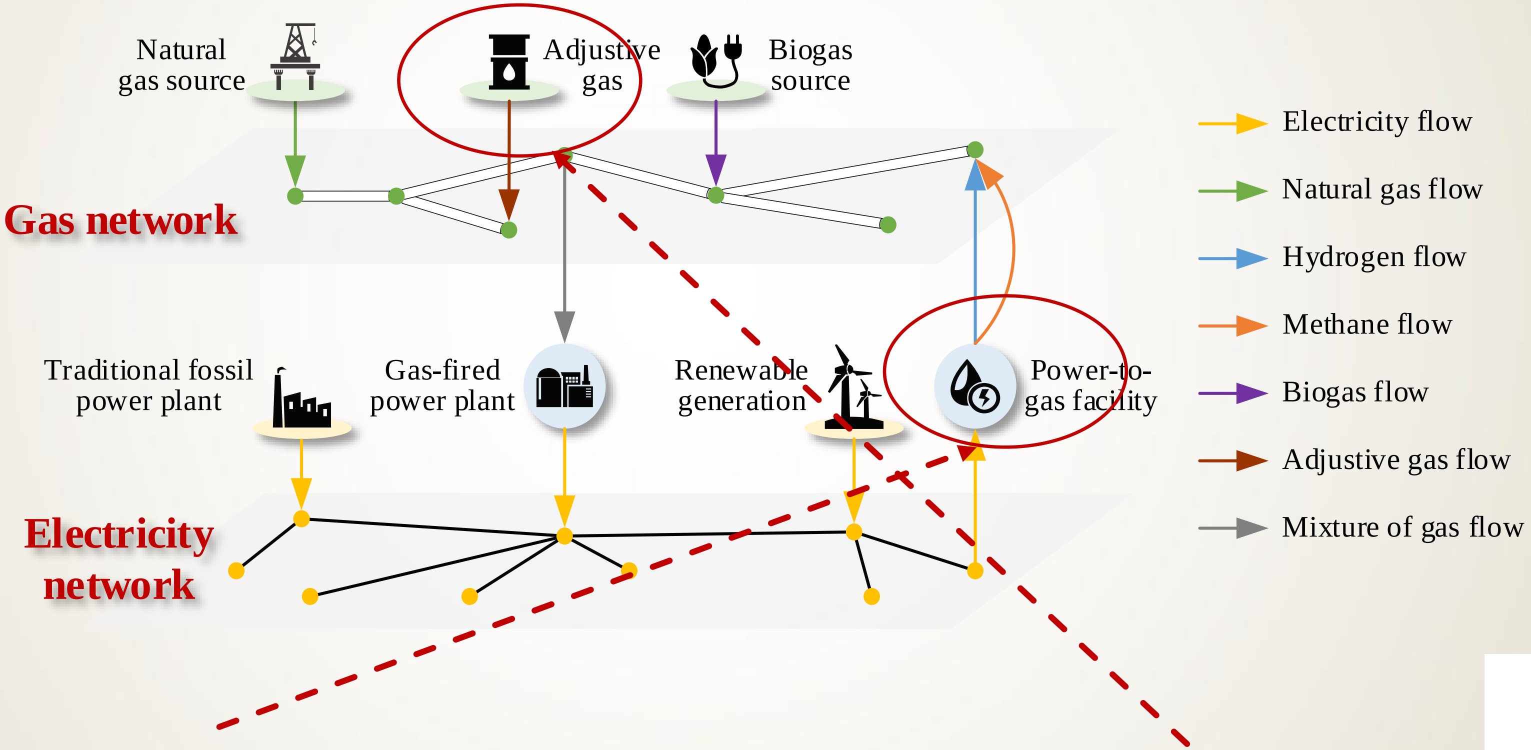
$$q_{i,l}^{hy}, q_{i,l}^{me} \ge 0$$



Contents

Risk mitigation scheme

---- How to mitigate risk



Regulate PTGs

- Hydrogen and methane

Use adjustive gases

- Liquefied petroleum gas (LPG) a

Risk mitigation scheme

---- challenges in the risk mitigation

- Varying physical properties

Weymouth equation

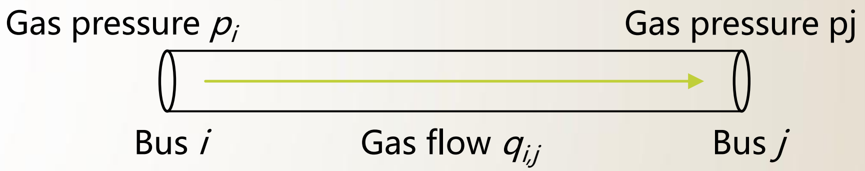
Property coefficient

$$q_{i,j}^2 = \frac{(T^{stp})^2\pi^2 R^{air} D_{i,j}^5}{64(p^{stp})^2 F_{i,j} S_{i,j} L_{i,j} Z_{i,j} T^{gas}}\gamma_{i,j}\underline{(p_i^2 - p_j^2)}$$

Pressure drop

Specific gravity

Compressibility factor

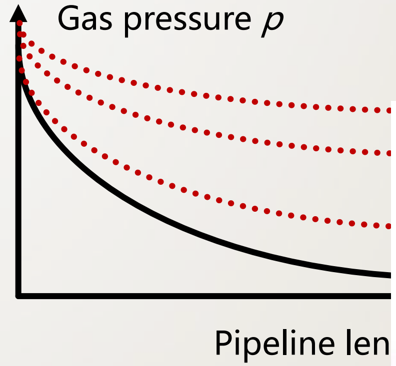


Traditional:

Constant

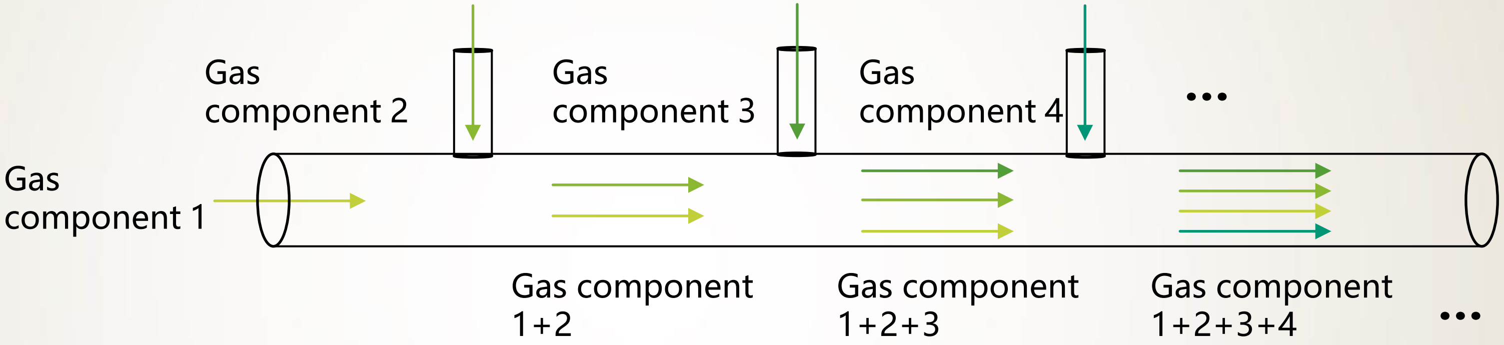
With hydrogen:

Variables



Risk mitigation scheme

---- challenges in the risk mitigation



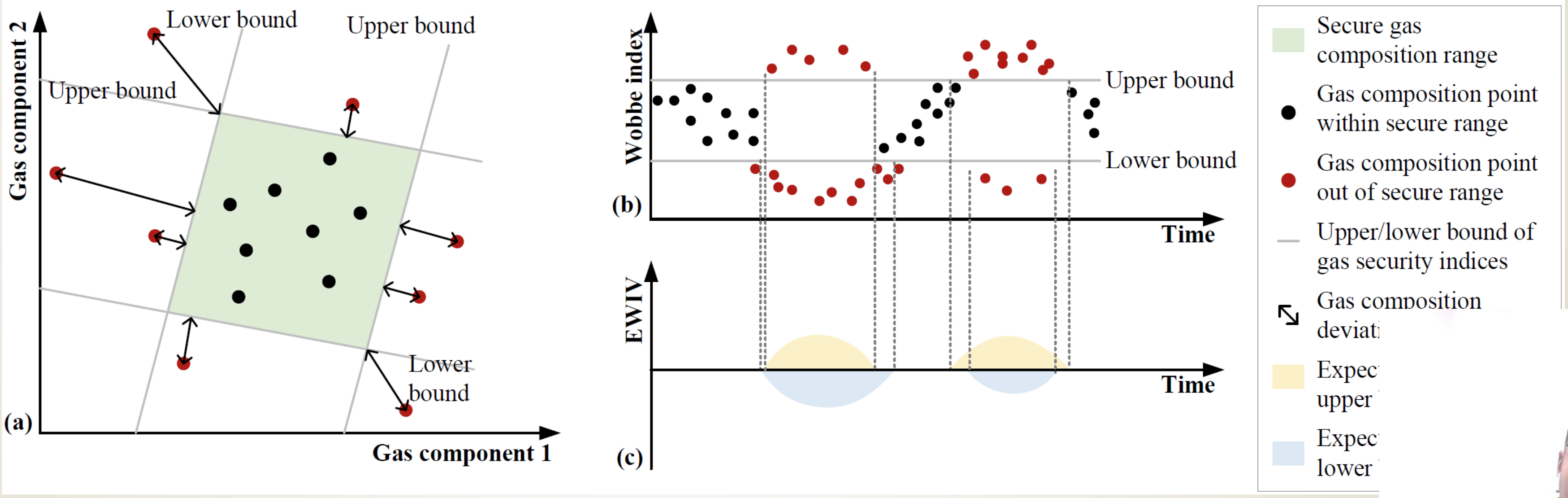
How to model this in a meshed gas network?

Contents

Operational risk indices

- Definition of gas system security

$$\mathbf{G} = \{\ \chi_i \mid WI_i^{min} \le WI_i \le WI_i^{max}, FS_i^{min} \le FS_i \le FS_i^{max}, GCV_i^{min} \le GCV_i \le GCV_i^{max}, S_i^{min} \le S_i \le S_i^{max}, \chi_i^{hy,min} \le \chi_i^{hy} \le \chi_i^{hy,max} \}$$



Operational risk indices

- UGF of gas risk

$$u^{WI,u}(z) = \Omega^{WI,u}\{u^{IPGS}(z_3)\} = \sum_{s\in\mathcal{S}}\sum_{i\in\mathcal{I}} \mathrm{Pr}^s z^{\delta\left(f^{WI}(\chi_i)-WI^{max}\right)}$$

$$u^{WI,d}(z) = \Omega^{WI,d}\{u^{IPGS}(z_3)\} = \sum_{s\in\mathcal{S}}\sum_{i\in\mathcal{I}} \mathrm{Pr}^s z^{\delta\left(WI^{min}-f^{WI}(\chi_i)\right)}$$

- Risk evaluation (expected Wobbe index violation (EWIV))

$$EWID^u(t) = \frac{\partial u^{WI,u}(z)}{\partial z},\ EWID^d(t) = \frac{\partial u^{WI,d}(z)}{\partial z}$$

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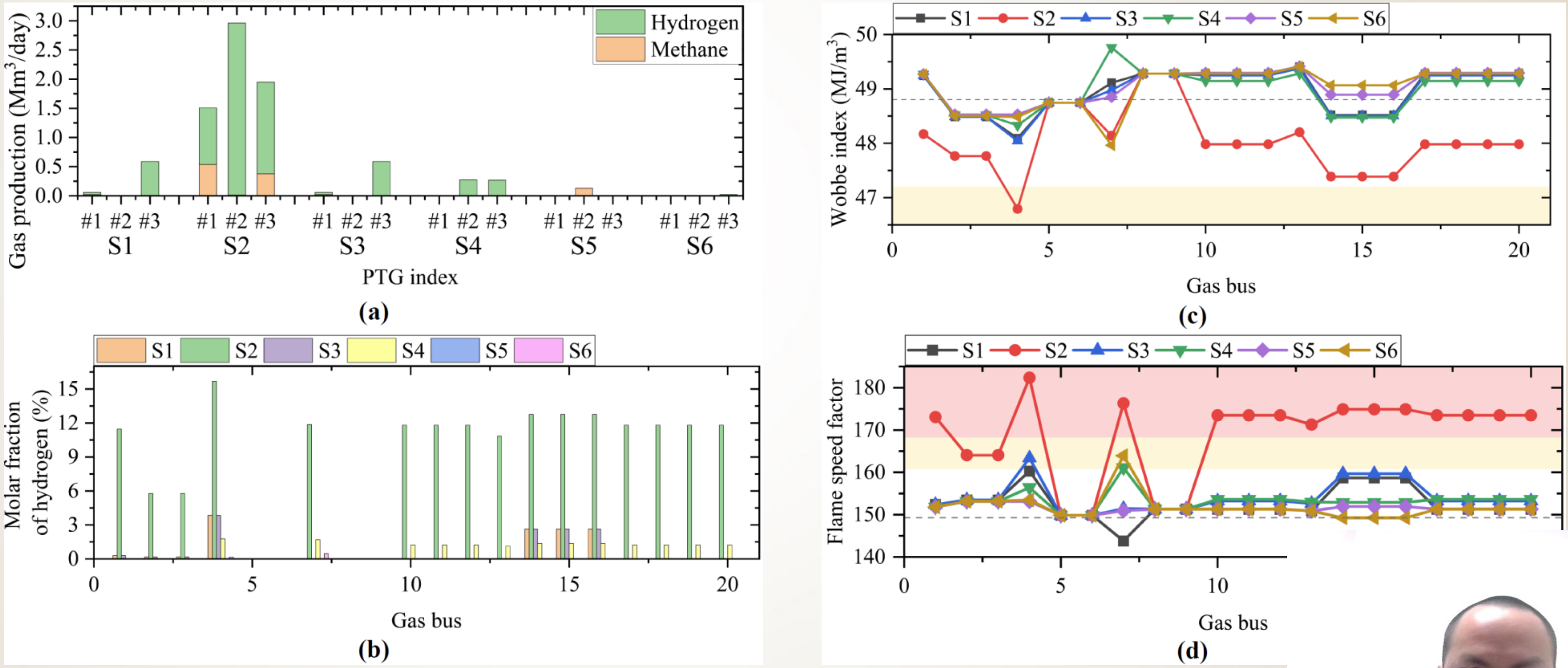
- **Case Studies**

Case Studies

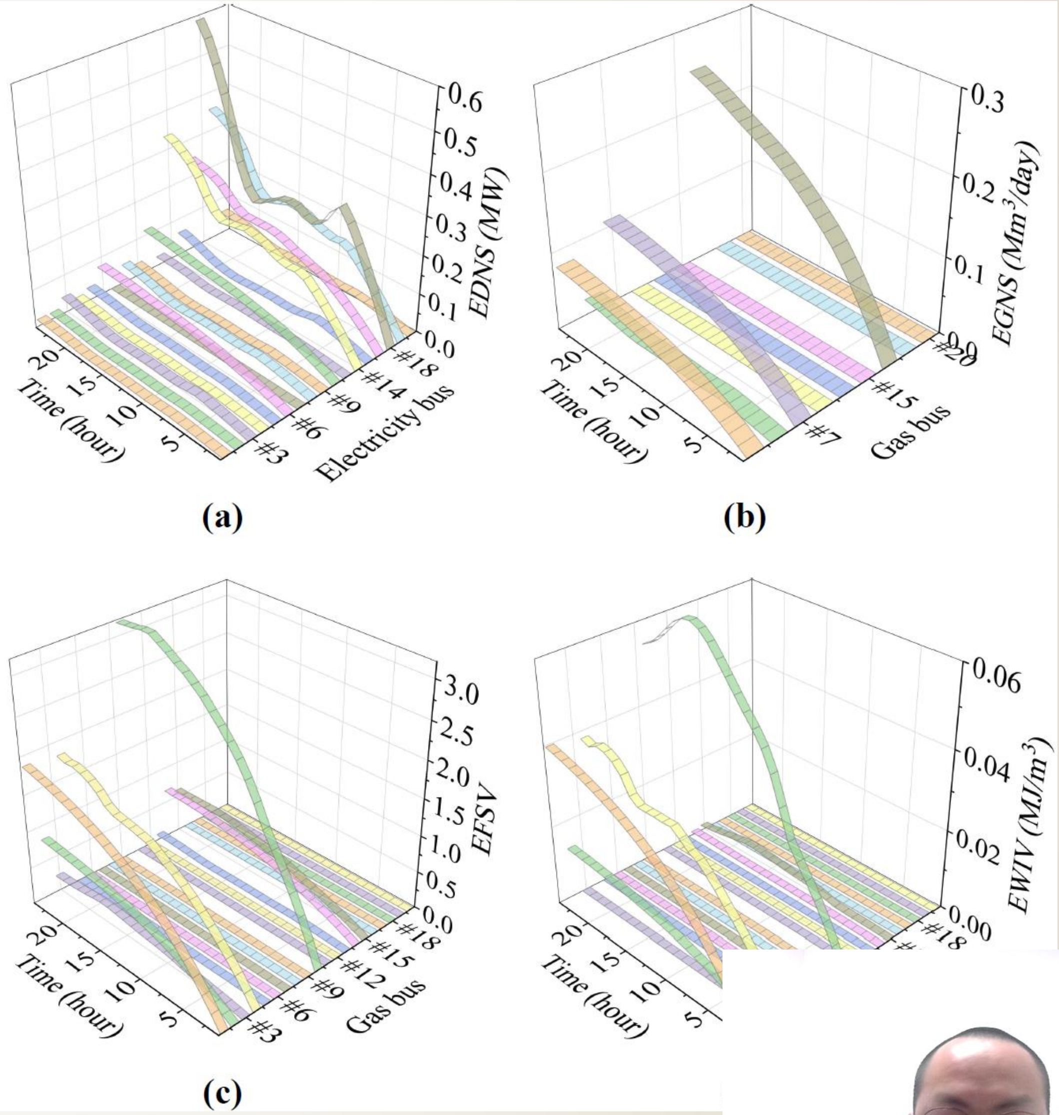
---- Operating conditions of the IPGS



Case Studies

---- risk indices

- from the spatial dimension, different buses present different reliability patterns.
- From the temporal dimension, the reliability indices grow with time generally.



(a) (b)

(c)

Conclusions

- the proposed risk assessment approach can improve the computation efficiency significantly by 97.31%
- though injecting the alternative gas produced by renewable generations may increase the risk of gas security violation, it is still beneficial for IPGS reliability in general. The EWIV and EFSV can be improved by 22.88% and 11.63%, respectively.
- With the growing concerns for the decarbonization of energy systems, the utilization of alternative gas will attract more attention in the future. However, the risk that comes with the alternative gas can not be omitted. The proposed short-term reliability evaluation method can provide an effective tool for the system operator to manage the reliability alternative gas injections.

Thank you!