Section C: Detailed Project Plans By Work Package

C1 WP1: Mass and Volume Flow Measurements

*(**FORCE,** CESAME, CMI, JV, SP, VSL, Shell)*

Start month: Jun 2014, end month: Mar 2017

LNG flow meters are available and ready to be used for LNG custody transfer except for two critical missing elements. This work package aims to deliver these elements; the first is the availability of calibration standards and the second is the availability of a written standard that can be referred to in industry.

The first aim of this work package is to develop a LNG mass flow calibration standard to provide traceability to the small and mid-scale LNG market. A flow loop will be constructed and validated that can run up to 100 m^3/h and which will be traceable to the primary LNG mass flow standard developed by VSL in the preceding JRP, ENG03 LNG. The flow loop will be designed to facilitate upgrading to 200 m^3/h (1300 kg/min) and 400 m^3/h (2600 kg/min). A commercial LNG composition measurement system will be integrated in the design together with LNG composition reference systems developed in WP2. Accurate composition measurements and density calculations can be used to convert the mass flow standard into a volume flow reference standard.

A Laser Doppler Velocity (LDV) flow measurement system will be built and validated under real conditions, for example at the aforementioned flow loop or at an alternative LNG location. This work is building upon the successful completion of the feasibility study in the preceding JRP, ENG03 LNG. The LDV system will provide an alternative traceability route for LNG volume flow meters. It can also be used as a facility or instrument to perform flow profile measurements.

The experience with the flow calibration standards will be combined with usage experience from stakeholders and from the field-experiments carried out in the preceding JRP, ENG03 LNG in order to draft an ISO standard for LNG flow meters.

The work of this technical work package will lead to the submission for publication of at least three peer reviewed papers. These papers are included in WP5 as D5.1.7; however the resource is included in this WP.

C1.a <u>Description of Work</u>

<u>Task 1.1: Design and construction of mid-scale LNG flow standard (**VSL**, FORCE, SP, CMI, Shell)</u>

(Start Jun 2014, end Oct 2015)

The aim of this task is to design and construct a mid-scale flow standard for calibrating LNG mass flow and volume flow meters. The system will be designed for flow rates up to 200 m^3/h (1300 kg/min) with an option to extend it, up to 400 m^3/h. In this Task a prototype will be built for flow rates up to 100 m^3/h (650 kg/min) using two alternative design principles.

VSL's contribution to Task 1.1 is not funded by the EMRP but will receive funding through a TKI Gas innovation programme in the Netherlands and through industrial support. Please see section B1.e for further details.

Description of activities:

- A preliminary design will be made for the mid-scale LNG flow standard for calibrating LNG mass flow and volume flow meters that comprises the functional design specifications, conceptual engineering, process flow diagrams, valve logic and an equipment list with budget pricing totals. Safety design consequences will be studied in a HAZOP study. To do this the following steps will be undertaken:
    - VSL with input from CMI and Shell will produce a functional design specification document for the mid-scale LNG flow standard. (VSL, CMI, Shell) (D1.1.1)
    - Using input from the previous activity, VSL and SP will produce a HAZOP study report and preliminary QRA (Quantitative Risk Assessment) for the mid-scale LNG flow standard. (VSL, SP) (D1.1.2)

- Using input from D1.1.1, VSL with input from FORCE and CMI will develop metrological design rules for detail engineering for the mid-scale LNG flow standard and record this in a document. (VSL, FORCE, CMI) (D1.1.3)
- Using input from D1.1.1, VSL in collaboration with FORCE and Shell will produce a Process and Instrumentation Diagram (P&ID) for the mid-scale LNG flow standard. (VSL, FORCE, Shell) (D1.1.4),
- Using input from D1.1.1 – D1.1.4, VSL with input from FORCE will produce a Control Systems Functional Specification, equipment list and specifications for the mid-scale LNG flow standard. (VSL, FORCE) (D1.1.5)
- Using input from D1.1.4 and D1.1.5, FORCE with input from VSL will produce a data acquisition architecture and functional design specification for software for the mid-scale LNG flow standard. (FORCE, VSL) (D1.1.6),
- VSL will develop a Facility Plot Plan, Equipment Layout Diagrams, the preliminary specifications for a bid, a cost estimate and schedule based on 15 % accuracy, and will issue the purchase orders for long lead items (e.g. vessels, pumps) for the mid-scale LNG flow standard. (VSL) (D1.1.7).

- The detail engineering will take place on basis of the previous activities. The P&ID and equipment list will be used to draw Isometric diagrams, detail piping and hookup-drawings for instrumentation. Piping support strength calculations, skid detail design will be performed. After delivery of isometric diagrams a flow pulsation-simulation study will be carried out. Requests for quotations based on final specifications, consultations with manufacturers and JRP-Partners will be carried out. Quotations will be reviewed and assessed on the basis of the finalised costs. The following steps will be undertaken:
  - Using input from D1.1.1 – D1.1.7, VSL with input from FORCE and SP will produce a detail engineering package with iso, piping, hookup, and 3D drawings for the mid-scale LNG flow standard. (VSL, FORCE, SP) (D1.1.8)
  - Using input from D1.1.5, VSL with input from FORCE and SP will produce a final equipment list and determine a 10 % accurate budget for the mid-scale LNG flow standard. (VSL, FORCE, SP) (D1.1.9)
  - Using input from D1.1.2, VSL together with SP and Shell will produce a final HAZOP study report and final QRA for the mid-scale LNG flow standard. (VSL, SP, Shell) (D1.1.10)
  - Using input from D1.1.8 – D1.1.10, VSL, together with Shell will make a go/no-go decision regarding the location and investment based on the 10 % accurate cost estimate for the mid-scale LNG flow standard. (VSL, Shell) (D1.1.11)
- The construction phase for the mid-scale LNG flow standard will start with the supply of materials. The overall construction will be realised by collaborator Oil & Gas Measurement Ltd (OGM), a company with extensive experience in constructing oil & gas fiscal metering systems. During construction VSL and other JRP-Partners will visit OGM in order to monitor quality and planning on site. A test program will be drawn up for factory acceptance tests (pumps, valves, flowmeters, coolers), electrical loop tests, valve logic, safety devices, software functionality and calculation codes. The following steps will be undertaken:
  - Using input from D1.1.8 and D1.1.9, VSL will place purchase orders for the equipment required for the mid-scale LNG flow standard and oversee the delivery of the equipment. (VSL) (D1.1.12)
  - Using input from D1.1.8 and D1.1.9, VSL with support from FORCE and SP will oversee the construction of the skid. Completion will be confirmed by email. (VSL, FORCE, SP) (D1.1.13)
  - Using input from D1.1.6 the functional design specification for software, FORCE with support from VSL will oversee the production by of the software for the mid-scale LNG flow standard. The software will be tested as part of the factory acceptance test program. (FORCE, VSL) (D1.1.14)
  - SP with support from VSL and FORCE will manage the factory acceptance test program and produce a factory acceptance test report for the mid-scale LNG flow standard. This will include a water functionality test report with focus on checking the performance of the master flow meters as built in (zero-ing, consistency and crosstalk tests). A report will be written. (SP, VSL, FORCE) (D1.1.15)

- Transport and installation for the mid-scale LNG flow standard involves the following preparation activities:
    - Using input from D1.1.10, SP with support from VSL will deliver a safety documentation package including the QRA, explosion safety document and certificates according to applicable European directives for the mid-scale LNG flow standard. (SP, VSL) (D1.1.16)
    - Using input from D1.1.13, SP with support from VSL will oversee civil and constructional preparation at the industrial site, transport of the skid and completion of the construction of the skid on-site. Completion will be confirmed by email. (SP, VSL) (D1.1.17)
- Commissioning for the mid-scale LNG flow standard at the industrial location will be done by SP with support from VSL and FORCE. Using input from D1.1.15, the JRP-Partners will test the leak tightness of piping, flanges and valves using cold nitrogen gas. The system will be filled with LNG to measure heat in-leak rates (effectiveness of insulation), to test operability of the pumps, subcoolers, flow meters and safety control. The results of commissioning will be reported in a commissioning report. (SP, VSL, FORCE) (D1.1.18)
- Using input from D1.1.15, SP, with support from VSL and FORCE will carry out functionality tests using liquefied natural gas to investigate and compare the flow stability using cryogenic pumps as well as a two-vessel flow generator principle. The behaviour of the flow meters (stability, reproducibility, zeroing) and overall functionality will be tested and a functionality test report will be produced for the mid-scale LNG flow standard. (SP, VSL, FORCE) (D1.1.18)

Major facilities to be used: none

<u>**Task 1.2: Upgrade and validation of the mid-scale LNG flow standard (VSL**, FORCE, SP, CMI, Shell)</u>

(Start Nov 2015, end Sep 2016)

The aim of this task is to upgrade the 100 m^3/h flow standard to 200 m^3/h (1300 kg/min) and to integrate a LNG sampler, vaporiser and GC system.

Description of activities:

- VSL, with input from FORCE, SP and Shell will analyse the results of the functionality testing (D1.1.18) in order to produce a final design and detail engineering drawings for the 200 m^3/h upgraded mid-scale LNG flow standard. (VSL, FORCE, SP, Shell) (D1.2.1).
- Using the design from the previous activity SP, FORCE and VSL will complete the reconstruction work on-site to upgrade the flow standard. The upgraded mid-scale LNG flow standard will be commissioned and a commissioning and site acceptance report will be produced. (VSL, FORCE, SP) (D1.2.2)
- VSL with support from SP, CMI, FORCE and Shell will validate the upgraded mid-scale LNG flow standard D1.2.2 for the mass flow range 10-200 $m^{3/}$h (65-1300 kg/min). The results will be analysed and a measurement uncertainty will be reported with a targeted uncertainty of 0.15 % for the mass flow. (VSL, SP, CMI, FORCE, Shell) A report will be written. (D1.2.3).
- VSL with support from FORCE and SP will integrate a commercial sampler, vaporiser and GC in the the upgraded mid-scale LNG flow standard D1.2.2. This will be compared against the LNG composition reference standard developed in D2.1.4 when integrated into the mid-scale LNG flow standard. Completion will be confirmed by email. (VSL, FORCE, SP) (D1.2.4)
- VSL with support from FORCE and SP will validate the integrated mid-scale LNG flow standard D1.2.4 and produce an uncertainty budget for the LNG volume flow calibrations up to 200 m^3/h with a targeted uncertainty of 0.2 %. (VSL, FORCE, SP) (D1.2.5).

Major facilities to be used:

Mid-scale LNG flow loop (VSL)

Task 1.3: Validation of flowmeters calibration curves and installation effects (VSL, FORCE, SP)

(Start Nov 2016, end Jan 2017)

The aim of this task is to investigate the possibility to extrapolate calibration results from low to high flow rates and from normal (water) to cryogenic (LN2, LNG) temperatures. This will answer the question of whether calibrations can be carried out in the most economic way and at what expense in terms of added uncertainty. Successful validation of extrapolation from low to high flow rate calibrations would provide insight to the uncertainties involved in the application of flow meters for large scale applications.

Description of activities:

- VSL with support from FORCE and SP will carry-out an experimental validation of extrapolation models for at least 2 types of mass flow meters and at least 2 types of volume flow meters. A report will be produced on the results of the validation. (VSL, FORCE, SP) (D1.3.1)
- VSL with input from FORCE and SP will investigate the installation effects (perturbed flow profiles and two-phase flow) for at least 1 mass and 1 volume flow meter. (VSL, FORCE, SP).
- Using input from D1.3.1 and the previous activity, FORCE in collaboration with VSL and SP will update the economic calibration procedure which was drafted in the preceding JRP ENG03. (FORCE, VSL, SP) (D1.3.2)

Major facilities to be used:

Mid-scale LNG flow loop (VSL)

Task 1.4: Cryogenic LDV standard (CESAME, CMI, JV, VSL)

(Start Jun 2014, end Mar 2017)

The aim of this task is to complete the prototype cryogenic LDV standard that was developed in the preceding JRP, ENG03 LNG for validation under real conditions. The previous study demonstrated that a target measurement uncertainty less than 0.2 % is realistic in cryogenic conditions. However, the system could be used as an alternative route for traceability of LNG flow measurements to fortify the metrological framework. The measurement system could also be used as an R&D facility for manufacturers to study flow distribution profiles and to investigate the magnitude of installation effects on the accuracy of LNG flowmeters.

Description of activities:

- CESAME will prepare a cryogenic LDV standard for testing based on the prototype produced in JRP ENG03 (CESAME) (D1.4.1). This will include the following steps:
    - Selecting the facilities for Liquid Nitrogen (LN2) and LNG tests
    - Manufacturing boxes for safe transport of the LDV measurement system to the experimental facilities
    - Finalising the implementation of seeding systems for cryogenic fluids LN2 and LNG tests
    - Validating the seeding system designed in feasibility study (2010-2013) under cryogenic conditions
    - Fitting the measurement system with temperature and pressure sensors and a vacuum pump for insulation purposes
    - Developing data acquisition and data post-processing for the measurement system
    - Defining and developing the means for flow visualisation (camera, laser sheet) in cryogenic conditions.
- CESAME will perform air based experiments with the aim of improving the accuracy of the LDV standard (D1.4.1). The air based experiments are based on the similarity of the flow at the same Reynolds number in the LDV measurement system under cryogenic (LN2 and LNG) and air flows. This will validate and optimise the geometry of the LDV standard and evaluate its uncertainty in simpler conditions (i.e. than cryogenic conditions). A report on the results will be produced. (CESAME) (D1.4.2)

- Using input from D1.4.2, CESAME will perform LN2 tests with the aim of validating the LDV standard (D1.4.1) using LN2 at Reynolds numbers <10^6 (small scale test) with a cryogenic flow loop at NIST. A report on the results will be produced. (CESAME) (D1.4.3)
- CESAME with support from CMI will perform flow simulations with the geometry of the LDV standard (D1.4.1). This will include:
    - Extrapolation of the results obtained in the feasibility study (2010-2013) to larger Reynolds numbers and by making use of the flow simulation to validate the industrial measurements of LNG flow rate by a local LDV measurement
    - Determination of velocity profiles and pressure distribution downstream the convergent
    - Velocity profile determination in LDV chamber for at least three different flowrates (Reynolds number > $5x10^5$) and at least two different LNG compositions
    - Optimisation of inlet nozzle shape for at least three different flowrates (Reynolds number > $5x10^5$) in order to obtain a flat profile
    - Comparison of OpenFoam and Fluent results
    - Estimation by means of flow simulations of the Heating of LNG from LDV laser power in the measurement volume
    - Estimation by means of flow simulations of subcooling needed for various laser powers and flowrates in order to avoid regasification
    - Flow simulations to characterise the heat transfer through the LDV optical windows and the temperature distribution in the optical windows
    - Flow simulations to characterise the distribution of refractive index on the path of LDV beams paths
    - Calculation of the influence of the distribution of the refractive index on the path of LDV beams
    - Calculation of the shift of position of the measurement volume and change of the interfringe of LDV

  From the results of the above, CESAME with input from CMI will produce a report on the flow simulations with the geometry of the LDV standard. (CESAME, CMI) (D1.4.4)

- CESAME will perform particle size characterisation of LNG and its dependence on source. The LDV standard (D1.4.1) needs micronic particles into the fluid to permit the measurement of the flow velocity necessary to determine the LNG flowrate. The aim is to determine the presence, the concentration and the characteristics of natural particles in the LNG for various supply sources. (CESAME) (D1.4.5)

- CESAME will carry out LNG tests with the aim of validating the LDV standard (D1.4.1) with LNG at Reynolds numbers <10^6 (small scale test) using a cryogenic flow loop (at VSL) or in an industrial setting (e.g. GDF Suez Montoir de Bretagne LNG terminal or the NIST liquid nitrogen flow calibration loop). After the initial validation of the LDV measurement system using air based experiments (D1.4.2), it must be validated in cryogenic conditions (LN2 and LNG). This means studying in cryogenic conditions: the behaviour of the mechanical parts of the prototype, thermal insulation systems, optical windows, the particle injection system, velocity measurement with the LDV and the accuracy of the LNG volume flowrate measurement. Completion will be confirmed by email. (CESAME, VSL) (D1.4.6)
- Using input from D1.4.1, D1.4.2 and D1.4.6, CESAME with support from JV will produce a report and uncertainty calculations for the LDV standard (CESAME, JV) (D1.4.7). The report will include
    - the uncertainty of the reference flowrate from the different reference flow loops used in the air based and/or cryogenic validations
    - the uncertainty of the velocity measured by the LDV standard
    - the uncertainty due to the influence of the optical windows, the pressure and temperature values of the fluids (air inside the vacuum insulation chamber & cryogenic fluid LN2 or LNG in the pipe)
    - the uncertainty of the volume flowrate

Major facilities to be used:

Mid-scale LNG flow loop (VSL)

C1.b Labour Resources for WP1

	1- VSL	2- CESAME	3- CMI	4- FORCE	5- INRIM	6- JV	7- NPL	8- PTB	9- SP	10- Shell	11- REG(RUB)	12- REG(TUBS)	TOTAL
WP1	23.0	24.0	11.0	11.0		7.0			8.5	1.0			85.5

C1.c Summary of Deliverables for WP1

Deliverable number	Deliverable description	Participants (Lead in bold)	Deliverable type	Delivery date	Dependent on
1.1.1	Functional design specification document for the mid-scale LNG flow standard	**VSL**, CMI, Shell	Document	Jun 2014	
1.1.2	HAZOP study report and preliminary QRA for the mid-scale LNG flow standard	**VSL,** SP	Report	Aug 2014	D1.1.1
1.1.3	Metrological design rules for detail engineering for the mid-scale LNG flow standard	**VSL**, FORCE, CMI	Document	Aug 2014	D1.1.1
1.1.4	Process and Instrumentation Diagram for the mid-scale LNG flow standard	**VSL**, FORCE, Shell	Technical drawing	Jul 2014	D1.1.1
1.1.5	Control Systems Functional Specification, equipment list and specifications for the mid-scale LNG flow standard	**VSL**, FORCE	Documents	Aug 2014	D1.1.1 to D1.1.4
1.1.6	Data acquisition architecture and functional design specification for software for the mid-scale LNG flow standard	**FORCE**, VSL	Document	Aug 2014	D1.1.4, D1.1.5
1.1.7	Facility Plot Plan and Equipment Layout Diagrams for the mid-scale LNG flow standard	**VSL**	Technical drawing	Aug 2014	
1.1.8	Detail engineering package with iso, piping, hookup, 3D drawings for the mid-scale LNG flow standard	**VSL**, FORCE, SP	Documents	Dec 2014	D1.1.1 to D1.1.7
1.1.9	Final equipment list for the mid-scale LNG flow standard	**VSL**, FORCE, SP	List	Dec 2014	D1.1.5
1.1.10	Final HAZOP study report and final QRA for the mid-scale LNG flow standard	**VSL**, SP, Shell	Report	Dec 2014	D1.1.2
1.1.11	Go-no-go decision (location + investment) on the mid-scale LNG flow standard	**VSL,** Shell	Document	Jan 2015	D1.1.8 to D1.1.10

1.1.12	Purchase orders for equipment placed for the mid-scale LNG flow standard	**VSL**	Document	Feb 2015	D1.1.8, D1.1.9
1.1.13	Confirmation that VSL, FORCE and SP have overseen the construction of the skid	**VSL**, FORCE, SP	Email	Apr 2015	D1.1.8 D1.1.9
1.1.14	Software for the mid-scale LNG flow standard	**FORCE**, VSL	Software	May 2015	D1.1.6
1.1.15	Report on factory acceptance test and water functionality test report for the mid-scale LNG flow standard	**SP**, FORCE, VSL	Report	Jun 2015	
1.1.16	Safety documentation package including the QRA, explosion safety document and certificates according to applicable European directives for the mid-scale LNG flow standard	**SP,** VSL	Documents	Jun 2015	D1.1.10
1.1.17	Confirmation that SP and VSL have overseen the construction of the on-site skid	**SP**, VSL	Email	Aug 2015	D1.1.13
1.1.18	Commissioning and functionality test reports based on LNG operation for the mid-scale LNG flow standard	**SP**, FORCE, VSL	Reports	Oct 2015	D1.1.15
1.2.1	Final design and detailed engineering drawings of 200 m^3/h for the upgraded mid-scale LNG flow standard	**VSL**, FORCE, SP, Shell	Documents	Nov 2015	D1.1.18
1.2.2	Commissioning and site acceptance report for the upgraded mid-scale LNG flow standard	**SP**, FORCE, VSL	Report	Apr 2016	D1.2.1
1.2.3	Report on analysed results of the validation with a targeted uncertainty of 0.15 % on mass flow for the upgraded mid-scale LNG flow standard	**VSL** ,SP, CMI, FORCE, Shell	Report	Sep 2016	D1.2.2
1.2.4	Confirmation of the integration of a commercial sampler, vaporiser and GC in the upgraded mid-scale LNG flow standard D1.2.2 and comparison with the LNG composition reference standard developed in D2.1.4 integrated into D1.2.2	**VSL**, FORCE, SP	Email	Apr 2016	D1.2.2, D2.1.4
1.2.5	Uncertainty budget for the LNG volume flow calibrations up to 200 m^3/h with a targeted uncertainty of 0.2 % for the integrated mid-scale LNG flow standard D1.2.4	**VSL**, FORCE, SP	Uncertainty budget	Aug 2016	D1.2.4
1.3.1	Report on the experimental validation of extrapolation models for at least 2 types of mass flow meters and 2 types of volume flow meters	**VSL**, FORCE, SP	Report	Nov 2016	
1.3.2	Updated economic calibration procedure	**FORCE**, VSL, SP	Procedure	Jan 2017	D1.3.1
1.4.1	Cryogenic LDV standard prepared	**CESAME**	Device	Nov 2014	
1.4.2	Report on the air based experiments with the LDV standard	**CESAME**	Report	May 2015	D1.4.1

1.4.3	Report on the LN2 tests with the LDV standard	**CESAME**	Report	Jan 2016	D1.4.1, D1.4.2
1.4.4	Report on the flow simulations with the geometry of the LDV standard	**CESAME,** CMI	Report	May 2016	D1.4.1
1.4.5	Particle size characterisation of the LNG and its dependence on source	**CESAME**	Dataset	May 2016	D1.4.1
1.4.6	Confirmation of the completion of the LNG tests for validating the LDV standard	**CESAME**, VSL	Email	Feb 2017	D1.4.1 D1.4.2
1.4.7	Report uncertainty calculations for the LDV standard	**CESAME**, JV	Report	Mar 2017	D1.4.1 D1.4.2, D1.4.6

C2 WP2: LNG Composition Measurements

*(**NPL**, CMI, SP, VSL, Shell, REG(RUB))*

Start month: Jun 2014, end month: Jan 2017

Accurate and traceable measurement of liquefied natural gas (LNG) composition is essential in order to accurately calculate physical properties used in the trade and transport of the energy gas. As the LNG share of the European energy budget grows, the financial implications of more accurate and reliable composition measurement also grows becoming much more impactful.

Due to physical state of LNG, the accurate measurement of LNG composition for trade / transport is significantly more challenging than that of gaseous natural gas (NG). This work package will investigate some of the issues and challenges associated with accurate composition measurement of bulk LNG. Information gathered from the previous EMRP JRP in this area will be used to assess the current 'state of the art' equipment used in industry and find where it can be improved.

The most accurate method to measure NG composition is by GC, and International Standards (the ISO 6974 series) exist for this. However in the case of LNG, the sampling of a liquefied gas into a homogenous gaseous state for analysis by GC is highly challenging – preferential sampling of one phase may occur, resulting in discrimination of the sample. Industrial measurements of LNG composition are currently being tested on-line by Raman spectroscopy in LNG pipelines but this is considered an unproven technology. Calculations to determine calorific value and density are based on gasified LNG which is analysed via GC in a similar way to NG. The aim of this work package is to investigate the issues in this area in two ways:

1. Methods to sample and vaporise LNG in a representative and homogeneous fashion will be developed in Task 2.2, while Task 2.1 will involve making an accurate, lab-based sampling and analysis reference method to test and calibrate commercially available systems.
2. Raman spectroscopy methods for composition analysis will be validated and compared with the results gained by those of GC methods in Task 2.3.

The effects of long-term storage (in terms of effect on LNG composition) will also be investigated in Task 2.4

Accuracy in the area of LNG composition analysis is currently a concern and no international intercomparisons have been performed on LNG composition analysis. This work package aims to produce a standard that will cover high accuracy sampling and measurement of LNG.

The work of this technical work package will lead to the submission for publication of at least two peer reviewed paper. These papers are included in WP5 as D5.1.7, however the resource is included in this WP.